Mass Wasting on the Queen Charlotte Islands: A Regional Inventory

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Land Management
Report NUMBER 29

ISSN 0702-9861

January 1988

BC

88-05571/

FISH/FORESTRY INTERACTION PROGRAM

This study was undertaken as part of the Fish/Forestry Interaction Program (FFIP), a multidisciplinary research study initiated in 1981. The program was started following a series of major winter storms in 1978 that triggered landslides over much of the Queen Charlotte Islands forest land base. Originating on steep slopes, many slides deposited tonnes of debris in streams and on valley flats. The events raised private and public concerns over logging practices on the Islands and prompted the establishment of the 5-year program. Overall objectives of FFIP were:

- to study the extent and severity of mass wasting and to assess its impacts on fish habitat and forest sites.
- to investigate the feasibility of rehabilitating stream and forest sites damaged by landslides.
- to assess alternative silvicultural treatments for maintaining the improving slope stability.
- to investigate the feasibility and success of using alternative logging methods, including skylines and helicopters, and by logging planning to reduce logging-related failures.

The program is jointly funded by direct appropriations from the Canada Department of Fisheries and Oceans, the B.C. Ministry of Forests and Lands (Research Branch), and the B.C. Ministry of Environment and Parks (Fisheries Branch). Participating agencies include the Canadian Forestry Service (Pacific Forestry Centre), and the Forest Engineering Research Institute of Canada (FERIC), Vancouver, B.C.

Program results are published through the B.C. Ministry of Forests and Lands, Land Management Report series, as well as in papers presented at symposiums, conferences, and through technical journals.

For information about the program contact Ministry of Forests and Lands, Research Branch, 1450 Government Street, Victoria, B.C. V8W 3E7.

Mass Wasting on the Queen Charlotte Islands A Regional Inventory

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January 1988

BC
Ministry of Forests
and Lands

Canadian Cataloguing in Publication Data
Gimbarzevsky, Philip
Mass wasting on the Queen Charlotte Islands

(Land Management Report, ISSN 0702-9861 ; no. 29)

Bibliography: p.
ISBN 0-7718-8619-5

1. Mass-wasting - British Columbia - Queen Charlotte Islands. I. British Columbia. Ministry of Forests and Lands. II. Title. III. Series

QE598.5.C3G55 1988 551.3'53'0971131 C88-092039-4

© 1988 Province of British Columbia
Published by the
Research Branch
Ministry of Forests and Lands
31 Bastion Square
Victoria, B.C. V8W 3E7

Copies of this and other Ministry of Forests and Lands titles are available at a cost-recovery price from the Queen's Printer Publications, Parliament Buildings, Victoria, B.C. V8V 4R5.

ABSTRACT

This report provides a regional inventory of the occurrence and frequency of landslide activity on the Queen Charlotte Islands. The survey was based entirely on a systematic analysis of small scale (1:50 000) panchromatic aerial photographs. Working procedures involved: delineation of drainage basins affected by mass movement activity, identification of slope failures, plotting interpreted details on 1:50 000 scale National Topographic System (NTS) map, and recording slope failure data by individual NTS map sheets within the "active" segments of the drainage basins and by 1-km^2 Universal Transverse Mercator (UTM) grid cells. Each UTM cells was classified by nine dominant landscape attributes (physiography, precipitation, biogeoclimatic zone, bedrock geology, land use, elevation, steepness, aspect and position on the slope), and according to the number of slope failure initiation points, placed into 11 corresponding frequency classes.

A total of 8328 individual debris slides, debris avalanches, debris flows and debris torrents were identified in 3153 UTM cells within the 2553 km^2 "active" segments of drainage basins. The survey results were presented on a 1:250 000 scale overview map, "Slope Failure Intensity", which displays the concentration levels of landslides in 3153 UTM cells expressed as three intensity classes: Moderate (one to three failure per square kilometer), Severe (four to seven failures per square kilometer), and Extreme (more than eight failures per square kilometer). About 75% of the area affected by slope failures is in the Moderate intensity class, 23% is in the Severe, and the remaining 2% is in the Extreme intensity class, with 8-18 failures per square kilometer. The mean failure frequency was 2.64 for all "active" 1-km^2 UTM cells, and 3.26 failures per square kilometer for the drainage basins "active" areas.

The analysis of frequency patterns in UTM cells grouped into nine classes of landscape attributes indicates a strong correlation of landslide intensity with topographic, physiographic, and climatic characteristics of the landscape. The most significant factor that exerts a strong influence over the intensity level is usually a combined effect of topography, climatic conditions, and physical land characteristics.

ACKNOWLEDGEMENTS

This study was undertaken as part of the Fish/Forestry Interaction Program through a cooperative effort by the Pacific Forest Centre. A study of this nature could not have been accomplished without the assistance of others who participated in various phases of the data acquisition and presentation. These contributions are greatly acknowledged. John Senyk assisted with analysis of aerial photographs and identification of slope failure forms. Trudy Carson transferred aerial photography data to 1:50 000 scale NTS maps and Dennis Clarke assisted in compiling survey data and drafting. Doug Say plotted slope failures by UTM grid cells and A. Dawson assisted in the map compilation of these data. Dr. Mark Sondheim, B.C. Ministry of Environment and Parks, provided a statistical analysis of UTM cells by frequency classes and landscape characteristics.

Thanks are extended to Jim Schwab for supplying the large scale photography used in the study, and for providing valuable suggestions and advice; and to Dr. Lee Beaven for his cheerful cooperation and assistance. I am especially grateful to the FFIP program manager Vince Poulin who recognized the importance of this component and has continually provided perspective and support.

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1 INTRODUCTION

Mass wasting constitutes the dominant geomorphic process in the coastal regions of British Columbia. The term "mass wasting" encompasses a variety of slope movement processes by which masses of soil, rock, and debris are transported downslope primarily by gravity. On the Queen Charlotte Islands, which comprise some of Canada's most valuable forest land, the combination of high rainfall, strong winds, and steep slopes -- exacerbated by seismic and human activities -- results in an unusually high intensity of slope movement. Mass wasting in mountainous terrain on the Queen Charlottes occurs in the form of rock and debris slides, debris avalanches, debris flows, debris torrents, and slump-earth flows. Through these processes, large quantities of eroded materials are transferred from the hillslopes to lower elevations, where they reduce the productivity of forest sites and change the morphology and habitat charactersitics of important sport and commercial fish-bearing streams.

In light of the potential severity of slope failure impacts on forestry and fishery resources, the joint Federal-Provincial Fish/Forestry Interaction Program (FFIP) was initiated in 1981 (Poulin 1983). The program incorporates a series of interdisciplinary research projects designed to investigate mass wasting processes and impacts on the Queen Charlotte Islands, and to develop practical resource management tools. One of the program's major objectives was to document the extent of mass wasting on the Queen Charlottes through the interpretation of both small and large scale aerial photographs. This study presents a regional overview of slope failures derived from analysis of small scale aerial photography.

The specific objectives of this study were to:

- document mass wasting processes on the Queen Charlotte Islands, based on a regional survey of slope failures from 1:50 000 scale aerial photographs;

- aid in the selection of representative study watersheds for other FFIP research components; and

- develop a data base for use by geologists, fisheries biologists, and resource managers working on slope stability problems on the Queen Charlotte Islands.

To achieve these objectives, the study was undertaken in two stages. The first involved a rapid analysis of 1979-1980 aerial photography to develop an overview showing the distribution and frequency of failures on a cross-island basis. The second stage involved a systematic analysis of dominant landscape characteristics and slope failure frequencies within Universal Transverse Mercator (UTM) cells (3145) that contained one or more slope failure initiation points.

2 STUDY AREA

The Queen Charlotte Islands, located 80 km off the central coast of British Columbia, are a scimitar-shaped archipelago extending for about 275 km in a northwest-southeast orientation. (Figure 1). Total area of the archipelago compiled, from 1:50 000 National Topographic System (NTS) maps, is approximately 10 000 km^2. Of the 2040 separate map entities representing the Queen Charlottes, only 503 are shown with geographical names, 385 of which are classified as "Islands", 66 as "Islets", and 52 as "Rocks". Two large islands, Graham in the north with an area of 6671 km^2, and Moresby in the south with an area of 2405 km^2, account for about 90% of the total area. The third largest is Louise Island with an area of 268 km^2. Some 26 other islands larger than 1 km^2 account for an additional 9% of the area. The remaining area (about 32 km^2) is occupied by 474 named and 1537 unnamed islands, islets, and rocks. The coastline of the archipelago is over 3070 km long. Graham and Moresby islands, which have a coastline of 1180 km and 1194 km, respectively, account for 77% of the total length.

The Queen Charlotte Islands were glaciated during the Pleistocene period and the present landscape is dominated by rugged mountain ranges on the west and south, and lowland plains in the northeast. Physiographically, the Islands are part of the Western System of the Canadian Cordillera, with two major subdivisions: the Hecate Depression and the Insular Mountains. There are three well-defined natural physiographic regions: the Queen Charlotte Lowlands, covering the northeastern portion of Graham Island, the Skidegate Plateau, in the central part of Graham Island, and the Queen Charlotte Ranges, extending southeast from the southwestern part of Graham Island (Sutherland Brown 1960; Holland 1964). The bedrock consists of volcanic, sedimentary, and intrusive rocks, frequently exposed or mantled by a relatively thin cover of glacial and colluvial material (Sutherland Brown 1968). The soils are mainly ferro humic podzols, with organic and lithic soils occurring extensively (Farley 1979). The climate is characterized by cool summers, mild winters, high rainfall, and strong winds. Mean monthly temperatures reach a high of 18° and a low of 2°C. The annual precipitation, strongly influenced by a

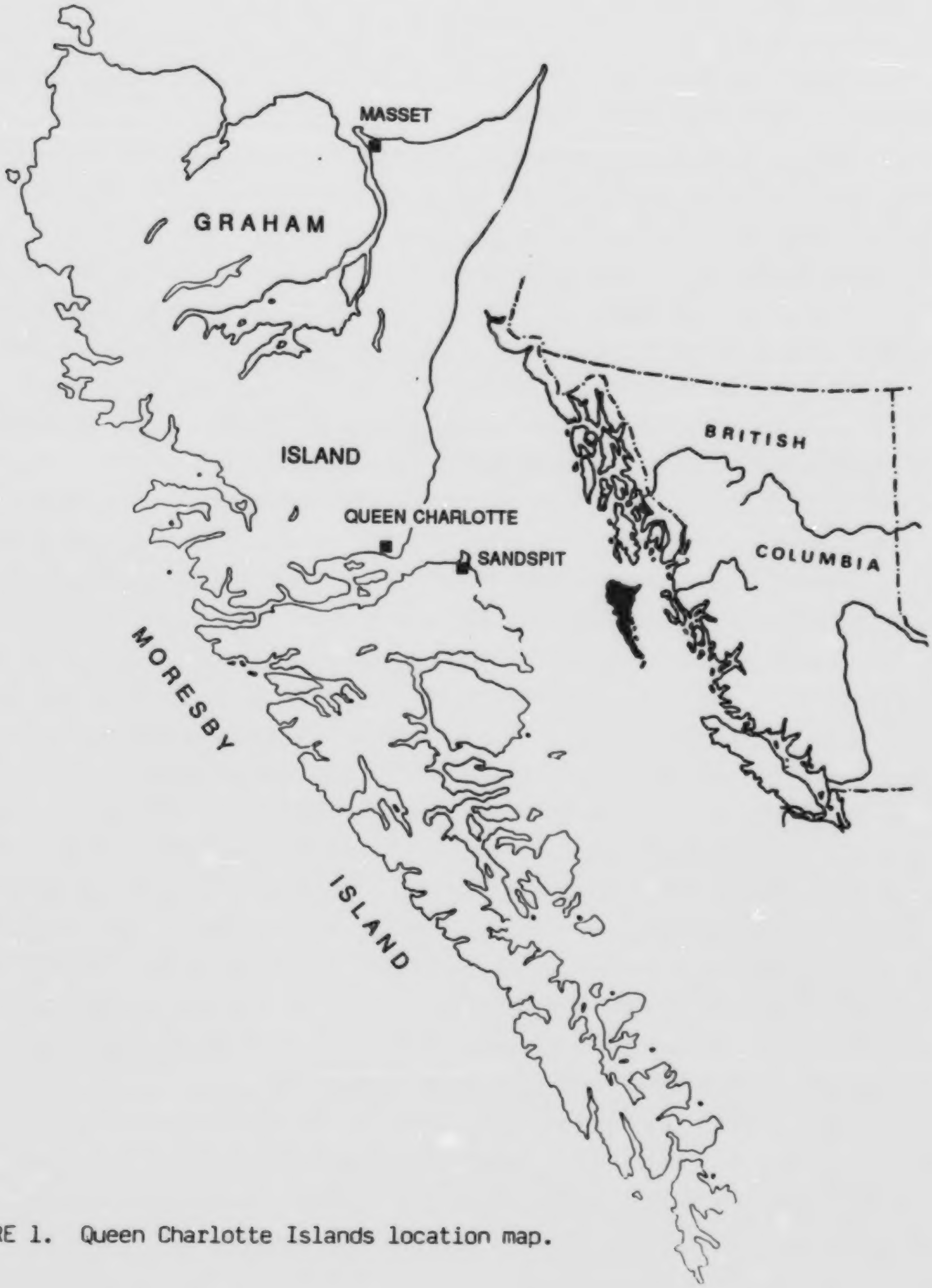
MASSET
GRAHAM
ISLAND
QUEEN CHARLOTTE
SANDSPIT
MORESBY
ISLAND
BRITISH
COLUMBIA

FIGURE 1. Queen Charlotte Islands location map.

diverse topography, ranges from about 4200 mm at Tasu Sound on the west coast, to 1150 mm at Sandspit, only 55 km northeast.

Most of the study area is forested and supports a good growth of merchantable forest stands. There are four biogeoclimatic zones: the Western Hemlock-Sitka Spruce Subzone (or Queen Charlotte subzone) of the Coastal Western Hemlock zone, the Coastal Cedar-Pine-Hemlock zone, the Mountain Hemlock zone, and the Alpine Tundra zone (Banner and Pojar 1982). Major tree species are western hemlock (*Tsuga heterophylla*), Sitka spruce (*Picea sitchensis*), western redcedar (*Thuja plicata*), yellow-cedar (*Chamaecyparis nootkatensis*), and red alder (*Alnus rubra*).

The freshwater resources of the Islands -- some 20 short rivers, numerous mountain streams, and over 1000 lakes and ponds -- provide valuable habitat for anadromous and residential fish populations. The lakes and ponds occupy about 106 km^2, or about 1% of the total area of the Islands. There are 62 lakes with geographical names shown on 1:50 000 scale NTS maps, occupying about 74.5 km^2, and 1016 unnamed lakes and ponds, covering an additional area of 31.6 km^2. Ian Lake on Graham Island, with an area of 16.96 km^2, or almost 1700 ha, is the largest freshwater body on the Queen Charlotte Islands.

3 STUDY DESIGN AND METHODOLOGY

The occurrence, distribution, and intensity of slope failure forms on the Queen Charlotte Islands was studied by stereoscopic analysis of small scale aerial photographs and analysis of data collected by FFIP. The work involved the following major steps:

1. Acquisition of aerial photography and topographic maps
2. Systematic airphoto analysis
3. Presentation of slope failures on topographic maps
4. Computation and listing of slope failures
5. Data reduction and compilation of slope failure overview map
6. Classification of 1-km^2 UTM grid cells according to nine basic landscape characteristics
7. Analysis and tabular summaries of UTM cells arranged by slope failure frequencies and dominant landscape characteristics.

3.1 Aerial Photography and Topographic Maps

The most recent small scale aerial photography (1:50 000 and 1:60 000) available for the Queen Charlotte Islands area was flown in summer 1979 and 1980 using a 152 mm focal length aerial camera at 8380 m ASL. Nineteen flight lines cover the entire area, except for approximately 900 km^2 in the northwestern parts of Graham Island (NTS 103-F/10, F/14, and F/15). To fill this data gap, the 1976 photography (scale 1:63 000) was used. For complete coverage of the study area, 500 prints or 480 stereo models were examined.

Two additional localized photo-missions were flown in 1981 and 1982: the Rennell Sound area, on the west coast of Graham Island (NTS 103-F/7E, -F/8W, -F/9W, and -F/10E), photographed in summer 1981 at a scale of 1:10 000, and some 20 additional watersheds, photographed in summer 1982 at the scale of 1:12 000.

Two scales of NTS maps (1:50 000 and 1:250 000) were used for this survey. To provide a complete coverage of all islands at the scale of 1:50 000, a total of 44 maps (east/west NTS sheets) were required, and two map sheets at the scale of 1:250 000.

The 1:50 000 scale, which was used for working maps, includes the NTS map sheets in Blocks 103 B, 103 C, 103 D, 103 G, 103 J, and 103 K (Figure 2). The southern tip of Kunghit Island, which extends into NTS 102-O/14, was added to the map above (NTS 103-B/3E).

For presentation of the overview, two 1:250 000 scale map sheets were used: NTS 103 B&C (Moresby Island) and NTS 103-F G, J, and K (Graham Island).

3.2 Analysis of Aerial Photographs

Photo-characteristics that indicate failing slopes include such features as landform, vegetation, photo-tone, texture, micro-topography, gullying and other pattern elements commonly used in terrain analysis. In the interpretation of slope movements, these features are usually assessed individually as well as and in combination with their shape, size, boundary characteristics, and spatial arrangement, as noted by Poole (1969), Rib (1978), Rib and Liang (1978), Foggin and Rice (1979), and other investigators.

The various forms of slope movements are generally described by the type and rate of movement and by the material involved (Swanston 1974; Varnes 1978; Ryder[1]). Based on these criteria and recent investigations of environmental geology and soil mass movements in coastal areas of British Columbia (Alley and Thomson 1978; Howes 1981; Wilford and Schwab 1982; Church 1983), the slope failures on the Queen Charlotte Islands may occur as one or a combination of the following forms: rock slides, debris slides, debris avalanches, debris flows, debris torrents, slump-earth flows, and snow avalanches.

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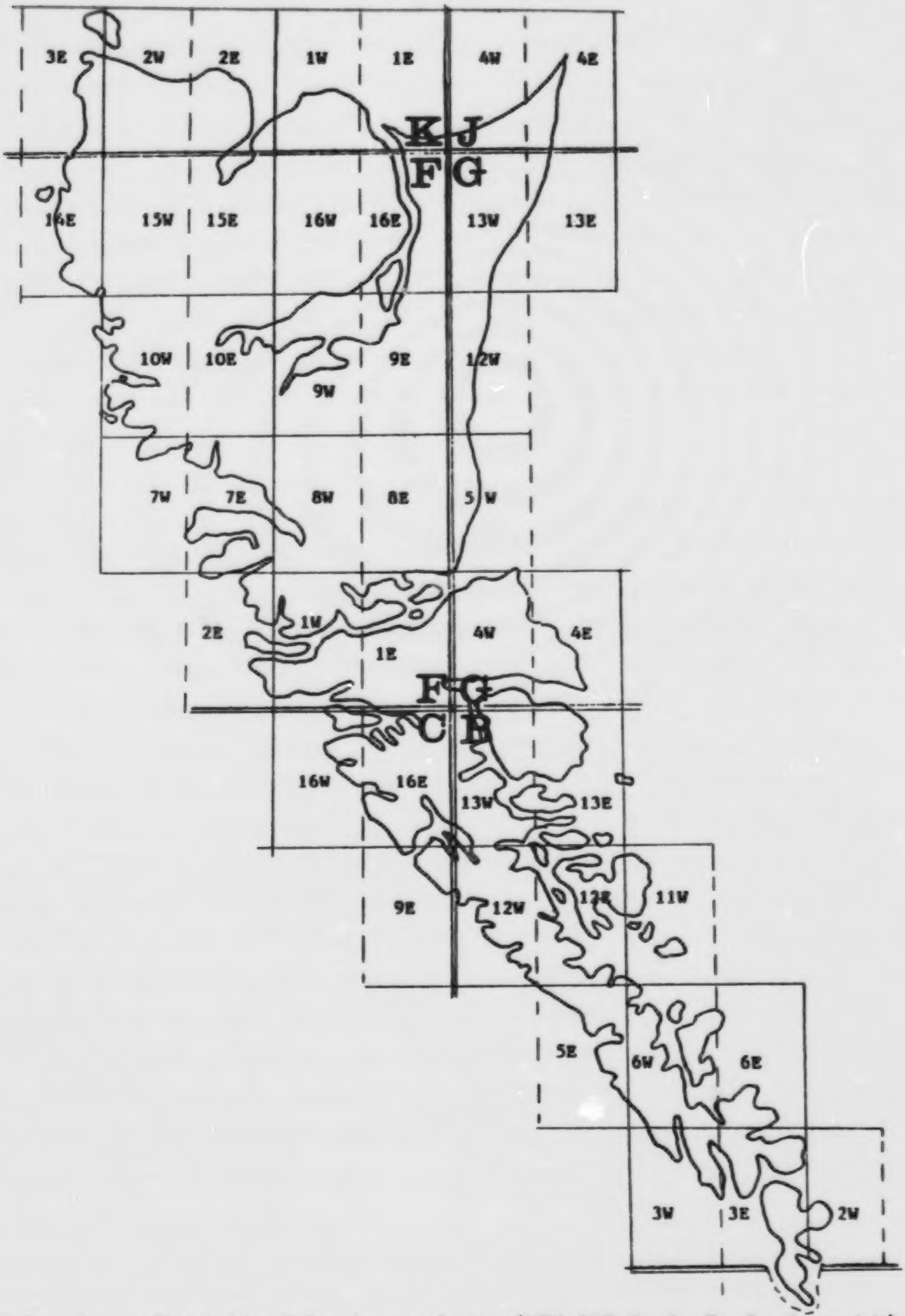
[1] Ryder, J. 1982. Mapping system for mass movement features: an extension of the terrain clasification system. Univ. B.C., Dep. Geo., Vancouver, B.C.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6E
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3E
2W

FIGURE 2. Queen Charlotte Islands map index (NTS 103 B, C, F, G, J, and K).

Recognizing slope movements on aerial photographs depends on size of failure, scale of photography, the time of year photography was done, and the type of film. While small scale photography (1:50 000 and smaller) is useful for documenting regional slope movements and mapping massive landslides (Dishaw 1967), medium (1:20 000) and large scale (1:5000) photography are usually required for identifying small landslides (Cleaves 1961). All recognized slope movement types for this analysis were mapped simply as "slope failure features." These included mainly well-defined recent, and some older, rock and debris slides on open slopes, debris flows, debris torrents, and avalanche tracks. Each failure was marked on the photograph by a line, indicating length, direction of movement, position on slope, and location within the landscape unit (Figure 3).

3.3 Mapping of Slope Failure Features

The transfer of slope failure features delineated on aerial photographs to 1:50 000 topographic maps was done using a Bausch and Lomb Zoom Transferscope. The planimetric and topographic details provided adequate control points for matching the photo scale with the map. The location of each slope failure was then transferred to the map as illustrated in Figure 4.

3.4 Computation and Cataloging of Slope Failures

The completed 1:50 000 scale topographic maps showing the location and distribution of identified slope movements were used as a working base to catalog the slope failure data shown in Figure 5. The slope failures within each map sheet were listed by corresponding map units delineated as drainage basins of individual streams or segments of watersheds affected by landslide activity. Occasional slides outside these map units were listed as "unclassified". Each map unit was referenced to either a known stream or the nearest geographic point, or was simply marked on the work map as "Area A", "B", "C", etc. The number of slope failures and the size

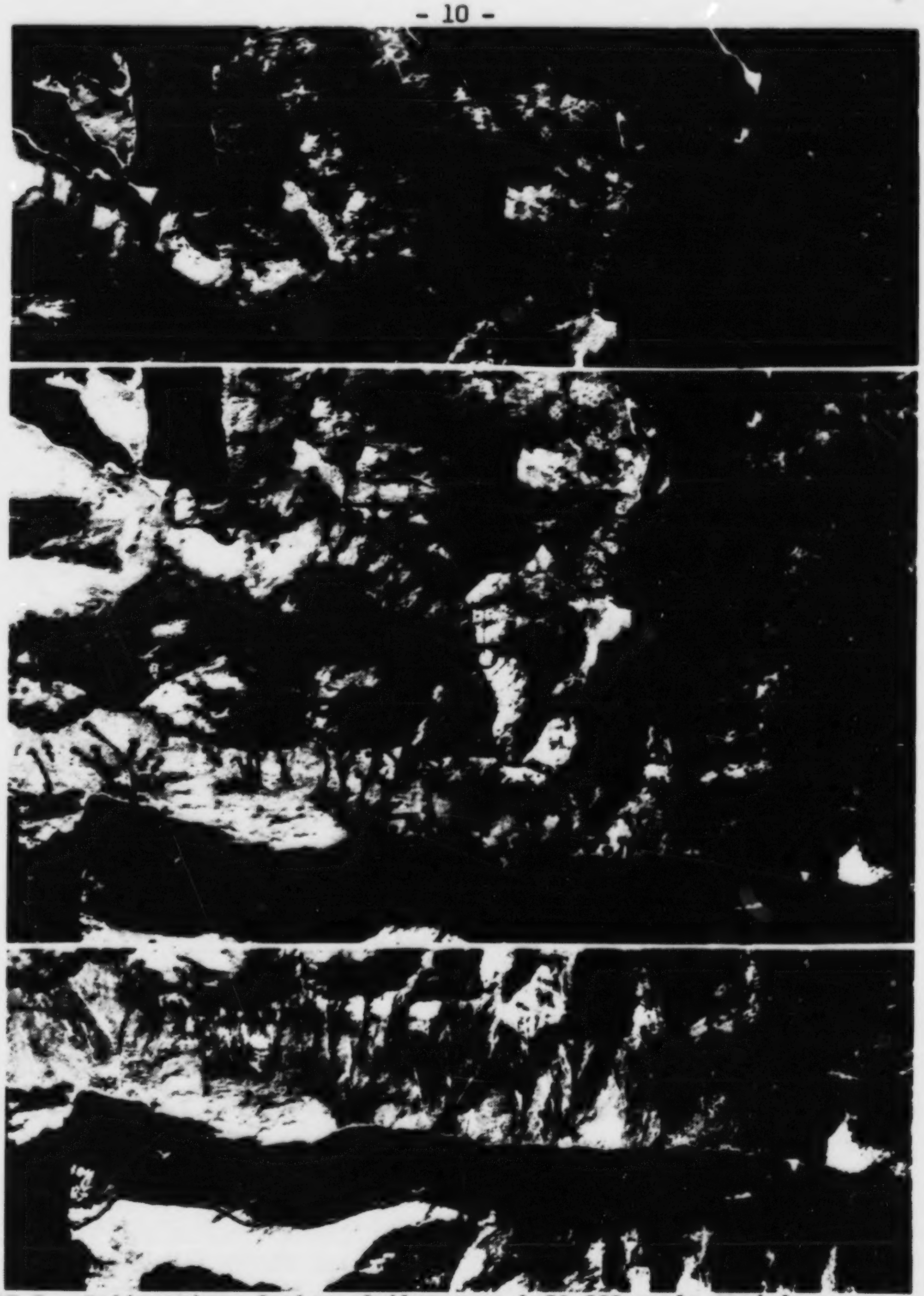


FIGURE 3. Delineation of slope failures on 1:50 000 scale aerial photographs. A stereogram (A 25291, Nos. 51-53, 22 Aug. 1979/Lens 152 mm), flying height 27,500 ft. ASL. Location: NTS 103-F/7E (Rennell Sound).

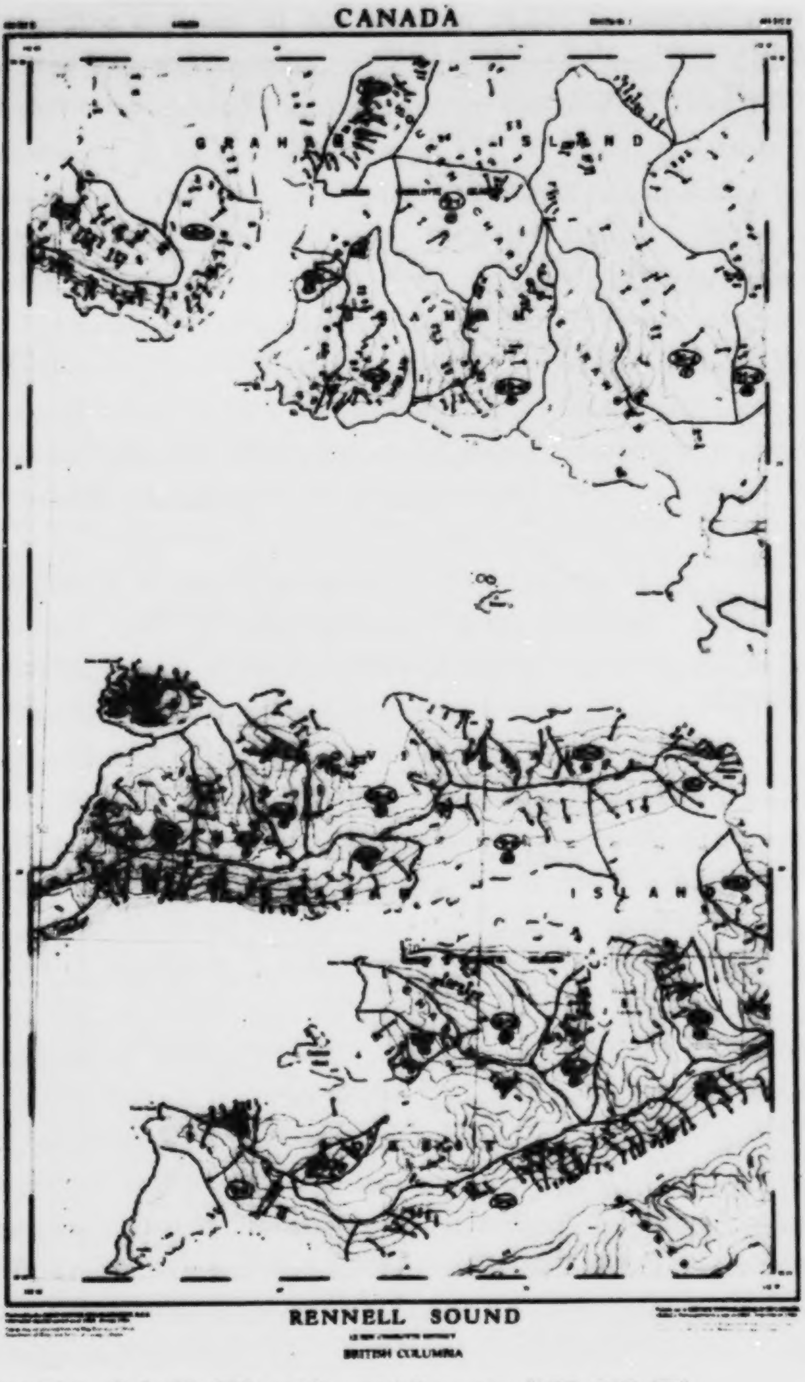

CANADA
GRAHAM ISLAND
ISLAND
RENNELL SOUND
BRITISH COLUMBIA

FIGURE 4. Example of 1:50 000 scale working map (NTS 103-7E).

SLOPE FAILURE SURVEY - QUEEN CHARLOTTE ISLANDS

NTS MAP SHEET: 103 -F/7E RENNELL SOUND

Area including inland water: 268.50 km^2

Inland water : .32 km^2

Land area : 268.18 km^2

Drainage or map unit area		Air Photo Numbers	No. of slope failures	Affected area in km^2	Frequency Failures $/km^2$	Number of Failures and Frequency	Land Use
Seal Inlet		A25291-18NW-57	31	6.9	5	31-5	F
Tartu Point		A25291-18NW-56	49	7.9	6	49-6	"
Tartu Inlet	A	A25291-16S-6	78	7.9	10	78-10	"
Tartu Inlet	B	"	9	7.3	1	9-1	"
Tartu Inlet	C	"	3	0.8	4	3-4	"
Rennell Sound	D	A25291-16S-8	41	4.9	8	41-8	"
Rennell Sound	E	"	29	7.2	4	29-4	"
Rennell Sound	F	"	36	16.9	2	36-2	"
Rennell Sound	G	"	41	16.9	2	41-2	L
Mt. Emmons N		A25291-18NW-54	9	1.1	8	9-8	F
Mt. Emmons S		"	13	1.3	10	13-10	"
Rennell Sound	H	A25613-20A-2	20	6.9	3	20-3	"
Rennell Sound	I	"	9	3.6	3	9-3	"
Rennell Sound	J	"	11	3.4	3	11-3	"
Rennell Sound	K	A25291-18NW-54	18	8.8	2	18-2	"
Rennell Sound	L	"	27	8.1	3	27-3	"
Cleonard Bay		A25291-16S-10	3	2.1	1	3-1	"
Kano Inlet	M	A25291-18NW-53	9	8.3	1	9-1	"
Kano Inlet	N	"	43	9.3	5	43-5	"
Kano Inlet	O	A25291-18NW-52	6	3.0	2	6-2	"
Kano Inlet	P	"	15	2.9	5	15-5	"
Kano Inlet	Q	"	16	5.2	3	16-3	"
Kano Inlet	R	"	9	1.3	7	9-7	"
Kano Inlet	S	"	6	0.9	7	6-7	"
Kano Inlet	T	"	5	1.1	5	5-5	"
Cartwright Sound		A25291-18NW-51	9	4.8	2	9-2	"
Van Inlet		"	71	13.4	5	71-5	"
Cleonard Bay		A25291-16S-10	4	2.1	1	4-1	"
UNCLASSIFIED			65				
TOTAL			685	166.3	4.2		

FIGURE 5. Slope failure survey - compilation sheet for NTS 103-F/7E.

of corresponding drainage or map units in square kilometers were obtained directly from the working maps. The listing also includes information on roll and print numbers of the photographs, and present land use in the map units, expressed as four broad classes: F = forested, L = logged, R = roads, and M = mining. All data were summarized to provide a total number of failures for each map sheet, the cumulative area (in square kilometers) of all affected drainage units and the average slope failure frequency.

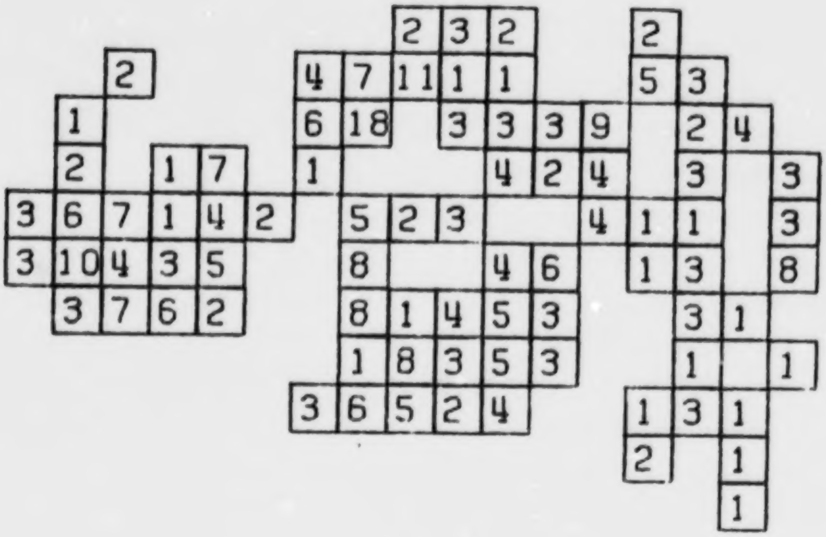
The landslide frequencies were also compiled by the UTM grid system. The initiation points of slope failure within the UTM grid cells were counted on the working maps and entered into a Bausch and Lomb BMP-29 plotter to produce a graphical printout showing number of slope failures within the 1-km^2 UTM grid cells (Figure 6).

3.5 Data Reduction and Compilation of Overview Map

Data reduction involved transferring of the slope failure features and the boundaries of affected drainage units from 1:50,000 scale work maps to the new base, and compiling an overview map at a reduced scale of 1:250,000. Because of the five fold reduction it was impractical to include all details from the original work maps. To make the overview map more legible it shows only the intensity of mass wasting processes expressed as a number of slope failures within the drainage units (Figure 7), and as three slope failure intensity classes, based on the frequencies of landslide initiation poiints in one-km^2 UTM grid cells (Figure 8).

A portion of 1:250,000 scale overview map, which includes the area illustrated in Figure 4, is shown in Figure 7. Figure 8 is an overview of slope failure intensities by UTM grid cells.

A complete set of NTS work maps photographically reduced to page-size, with compilation sheets and corresponding graphical printouts by the UTM grid cells was included in the FFIP Working Paper 3/83 as Appendix A. The originals are on file at the FFIP office in Vancouver.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3 10 4 3 5 8 4 6 1 3 8
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3 6 5 2 4 1 3 1
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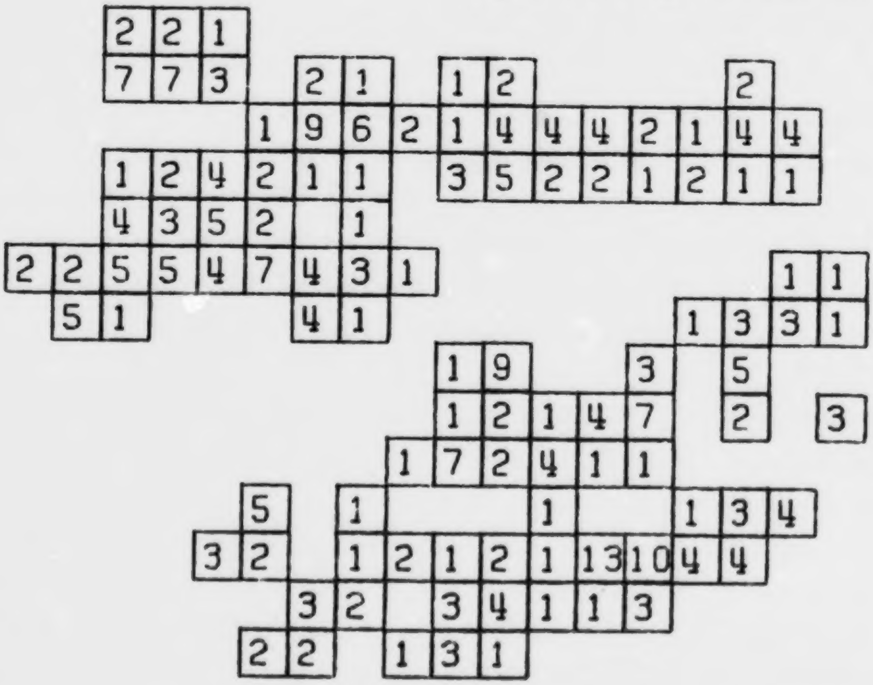
1

103 F/7 E **Rennell Sound**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1 9 6 2 1 4 4 4 2 1 4 4
1 2 4 2 1 1 3 5 2 2 1 2 1 1
4 3 5 2 1
2 2 5 5 4 7 4 3 1 1 1
5 1 4 1 1 3 3 1
1 9 3 5
1 2 1 4 7 2 3
1 7 2 4 1 1
5 1 1 1 3 4
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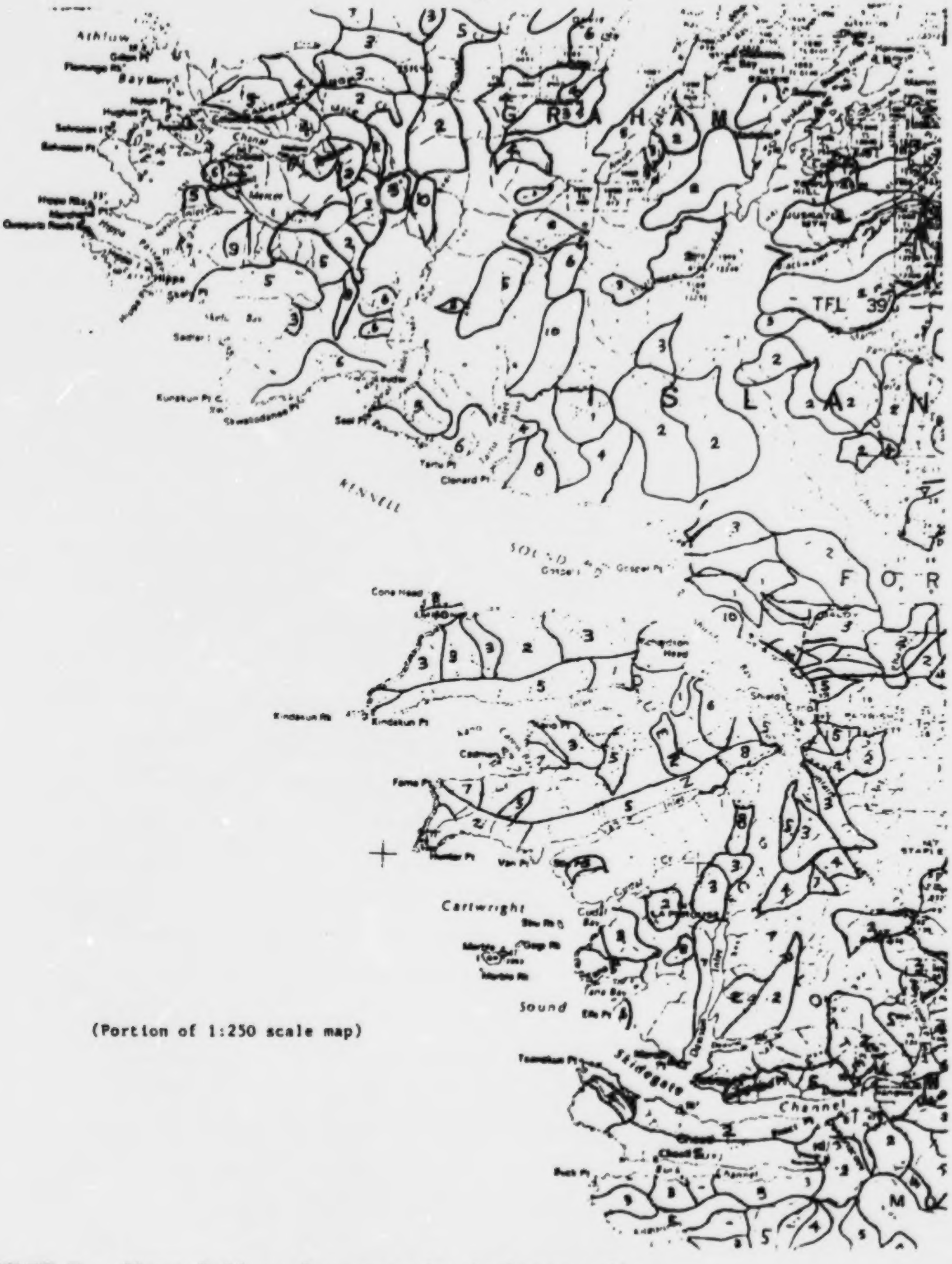
2 2 1 3 1

FIGURE 6. Landslide initiation points by UTM grid cells - NTS 103-F/7E.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GRAHAM
ISLAND
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FOR
Kennell Sound
Gospel Pt
Cone Head
Kindakun Pt
Cartwright
Sound
Skidegate Channel
Channel

(Portion of 1:250 scale map)

FIGURE 7. Slope failure frequency by drainage units.

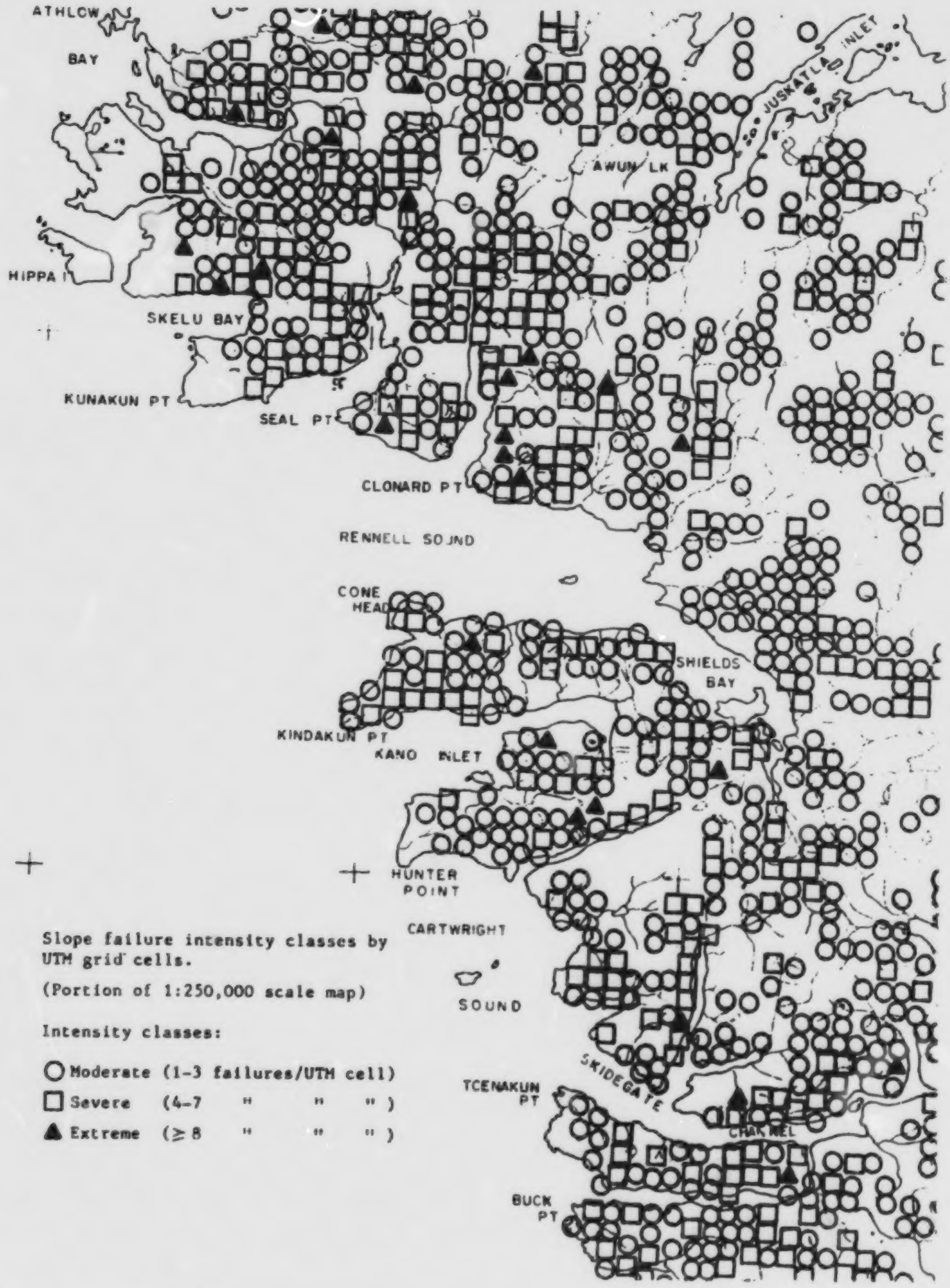
ATHLOW BAY
JUSKATLA INLET
AWUN LK
HIPPA I
SKELU BAY
KUNAKUN PT
SEAL PT
CLONARD PT
RENNELL SOUND
CONE HEAD
SHIELDS BAY
KINDAKUN PT
KANO INLET
HUNTER POINT
CARTWRIGHT SOUND
TCENAKUN PT
SKIDEGATE CHANNEL
BUCK PT
Slope failure intensity classes by UTM grid cells.
(Portion of 1:250,000 scale map)
Intensity classes:
○ Moderate (1-3 failures/UTM cell)
□ Severe (4-7 " " ")
▲ Extreme (≥ 8 " " ")

FIGURE 8. Slope failure intensity classes by UTM grid cells.

3.6 Slope Failure Frequency and Landscape Characteristics

During the acquisition of inventory data it became evident that the occurrence of slope failures and their concentration in various parts of the Queen Charlotte Islands were closely related to a combination of biotic and physical characteristics of a particular landscape unit (Gimbarzevsky 1983). The slope failures "active" UTM cells provided an excellent base for the systematic analysis of slope failure frequencies and dominant landscape characteristics.

3.6.1 Classification of UTM cells by landscape characteristics

To correlate the dominant landscape characteristics with the intensity of landslide activity, each of the 3153 UTM cells was systematically analyzed and classified by the following dominant attributes:

1. Physiography (3 major physiographic subdivisions and 10 regional areas)
2. Precipitation (4 precipitation zones)
3. Biogeoclimatic zones (4 zones)
4. Bedrock geology (12 rock formations)
5. Land Use (4 land use classes)
6. Elevation (7 elevation ASL classes)
7. Slope Steepness (5 slope steepness classes)
8. Aspect (8 slope direction or aspect classes)
9. Position on Slope (3 slope position classes).

With computer-assisted analysis, the UTM cells were grouped according to intensity of landslide activity within the above nine landscape characteristics, the work progressing as shown in the flow chart (Figure 9).

Each of the 3153 one-km^2 UTM cells presented on 1:50 000 scale topographic maps and on the Bausch and Lomb graphical plotter

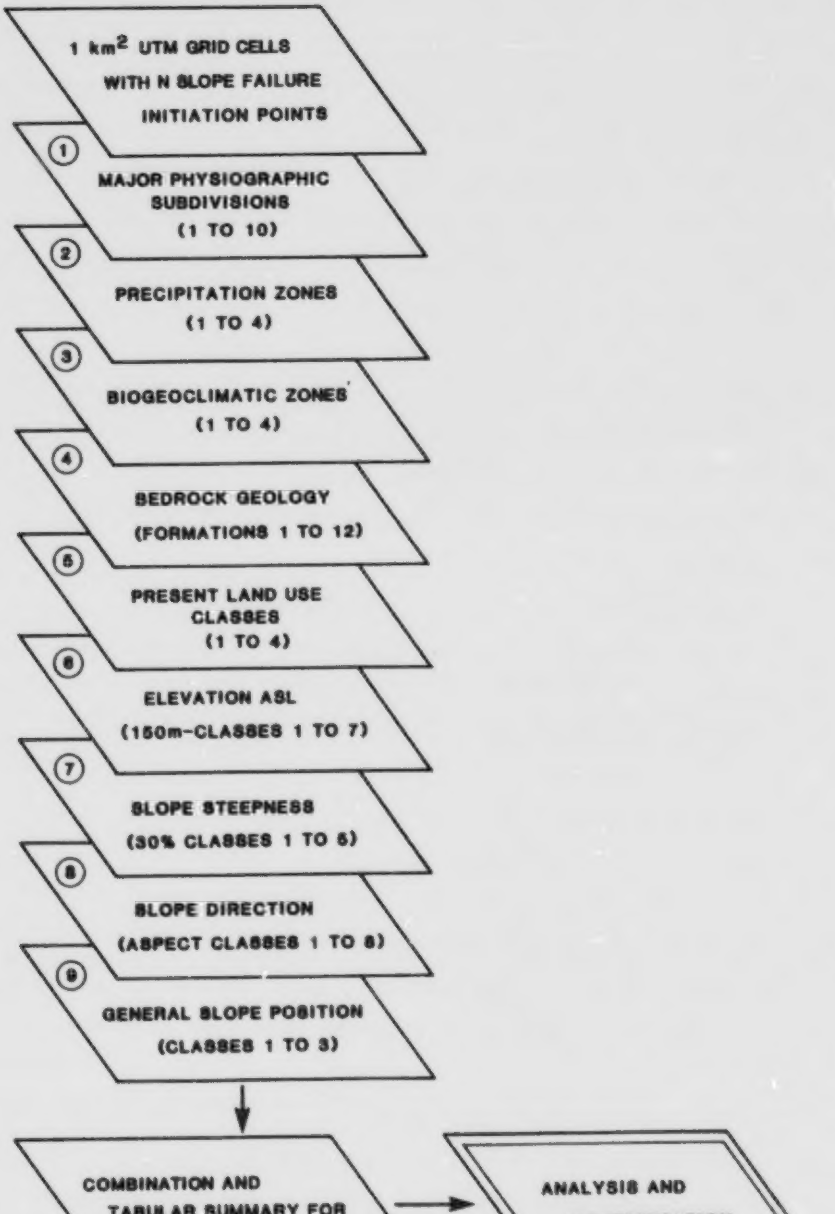
1 km^2 UTM GRID CELLS WITH N SLOPE FAILURE INITIATION POINTS
①
MAJOR PHYSIOGRAPHIC SUBDIVISIONS (1 TO 10)
②
PRECIPITATION ZONES (1 TO 4)
③
BIOGEOCLIMATIC ZONES (1 TO 4)
④
BEDROCK GEOLOGY (FORMATIONS 1 TO 12)
⑤
PRESENT LAND USE CLASSES (1 TO 4)
⑥
ELEVATION ASL (150m-CLASSES 1 TO 7)
⑦
SLOPE STEEPNESS (30% CLASSES 1 TO 5)
⑧
SLOPE DIRECTION (ASPECT CLASSES 1 TO 8)
⑨
GENERAL SLOPE POSITION (CLASSES 1 TO 3)
COMBINATION AND TABULAR SUMMARY FOR THE ENTIRE STUDY AREA
ANALYSIS AND INTERPRETATION

FIGURE 9. Classification and coding of individual 1-km^2 UTM grid cells by landscape characteristics.

printouts was analysed as shown in Figure 10. The listing commenced in the upper-left corner of each map sheet (Figures 11 and 12) and progressed to the right along the UTM grid "northing" line. Each tier of UTM cells was listed in the same sequence as it appears on the map to allow for easy checking of the actual number of landslide initiation points and corresponding classification codes.

A simple numeric coding was used for classification of each cell by nine landscape attributes numbered from 1 to 9 on the top of the compilation form, as shown in Figure 10. The first UTM cell, for example, listed on the compilation form of NTS map sheet 103-B/13W, has two slope failure initiation points. The description of this 1-km^2 area would be: It is part of the East Coast Mountains (Mixed Volcanics) regional physiographic area (8) of the Queen Charlotte Ranges Major Physiographic Subdivision; is located in the Queen Charlotte Subzone of Coastal Western Hemlock Biogeoclimatic Zone (1) with an extreme (class 4) mean annual precipitation of 3665-3775 mm (precipitation zone 4); is forested (land use class 1); and is located at an elevation of 451-600 m ASL (elevation class 4) on very steep (61-90%) upper slopes (3), underlain by hard volcanic bedrock of the Karmutsen Formation (9).

3.6.2 Computer-assisted compilation of summaries

Following the classification and coding of all UTM grid cells, the data recorded on the compilation forms were entered into a VAX 11/750 computer at the Pacific Forest Research Centre. A computer printout produced for each NTS map sheet provided a summary of all UTM cells grouped by the number of landslide initiation points (slope failure frequencies from 1 per square kilometer to 11+per square kilometer), and sorted by "landscape characteristics" (nine basic types and 57 sub-types) as listed on the left-hand margin of the printout shown in Figure 13.

The classification data, summarized by individual NTS maps, were then merged into a combined tabular summary of the entire survey area (Figure 21) for data analysis and interpretation.

Figure 10

NTS 103-B/B:W Page 1 of 8

Queen Charlotte Islands - Landslide Initiations in UTM cells by:

mber of initiation points in 1km^2 UTM cells	Physiographic subd. 1	Isonyetal zone 2	Biogeo-climat. zone 3	Bedrock formation 4	Land use class 5	Elevation class 6	Slope Steepness 7	Slope Aspect 8	Position on slope 9
2	8	4	1	9	1	4	3	6	3
① 6	4	3	3	10	1	5	3	8	3
4	4	3	1	10	1	3	3	6	3
1	4	3	1	10	1	1	2	3	1
2	7	3	1	1	1	1	2	7	1
2	8	4	1	9	1	2	3	6	1
2	8	4	1	9	1	4	3	8	3
6	8	4	3	9	2	5	3	6	3
1	8	4	1	9	2	3	4	6	2
② 3	4	3	3	10	1	5	4	8	3
1	4	3	3	10	1	5	3	2	3
5	4	3	1	10	1	3	3	4	2
3	7	3	1	10	1	2	3	8	1
4	7	3	1	10	1	3	4	3	3
1	7	3	1	10	1	1	2	3	1
1	7	3	1	10	1	2	2	5	2
3	7	3	1	6	2	3	2	2	3
5	8	4	1	9	1	3	2	4	3
5	8	4	1	9	1	4	4	6	2
2	8	4	3	9	1	5	3	8	3
6	8	4	3	9	2	5	3	6	3
③ 5	8	4	1	9	1	2	4	4	2
3	4	3	1	10	1	3	3	8	3
2	4	3	1	10	1	3	3	5	3
5	4	3	1	10	1	5	3	1	3
3	4	3	1	10	1	2	3	4	2
5	7	3	1	10	1	4	3	8	2
7	7	3	1	10	1	4	3	4	2
2	7	3	1	5	1	3	3	8	2
1	7	3	1	5	1	4	3	6	2

FIGURE 10. Compilation form used in coding UTM grid cells.

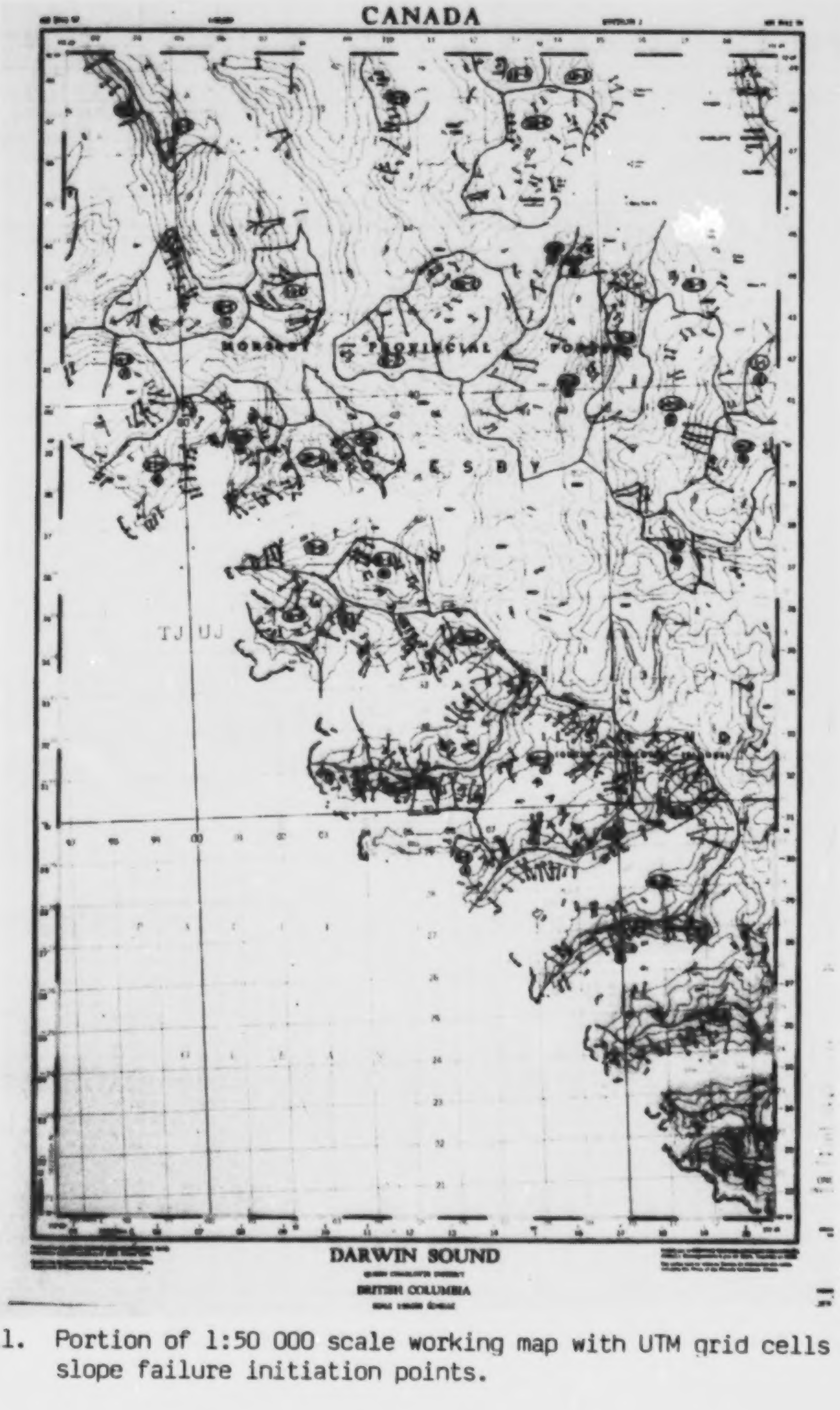
CANADA
MORESBY
PROVINCIAL
FOREST
TJ UJ
DARWIN SOUND
BRITISH COLUMBIA

FIGURE 11. Portion of 1:50 000 scale working map with UTM grid cells and slope failure initiation points.

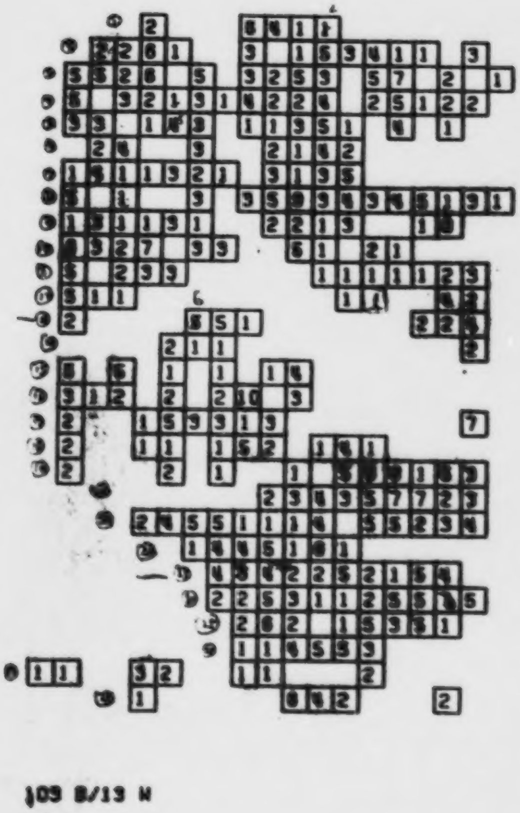

FIGURE 12. Graphical printout of UTM cells shown in Figure 11.

103- B/13 W

QUEEN CHARLOTTE ISLANDS - ANALYSIS OF SLOPE FAILURE FREQUENCIES
BY UTM CELLS AND LANDSCAPE CHARACTERISTICS NTS 103-B,13W

LANDSCAPE CHARACTERISTICS		NUMBER OF 1 KM**2 UTM CELLS CONTAINING N LANDSLIDES (N=1 TO 11+)												TOTAL	
		1	2	3	4	5	6	7	8	9	10	11+		SLIDES	CELLS
MAJOR PHYSIOGRAPHIC SUBDIVISIONS	1. SEDIMENTARY-NW														
	2. MIXED VOLCANICS-NW														
	3. PLUTONS-W	3		1										6	4
	4. PLUTONS-E	14	8	10	5	6	1			1				125	45
	5. MIXED VOLCANICS-SW														
	6. MIXED VOLCANICS-NE														
	7. MIXED SEDIMENTARY-E	21	14	12	3	9	1	2	1	1				179	64
	8. MIXED VOLCANICS-SE	34	32	21	18	25	5	3	3		2			453	143
	9. LIMESTONE														
	10. SED. UNDER GLACIAL DEP.														
PRECIPITATION ZONES	1. LOW (1260-1370 MM/YR)														
	2. MODERATE (1665-1765 MM/YR)														
	3. HIGH (2035-2225 MM/YR)	29	21	18	13	19	1	4	3	2				348	110
	4. EXTREME (3665-3775 MM/YR)	43	33	26	13	21	6	1	1		2			415	146
BIO-GEOCLIMATIC ZONES	1. COASTAL WESTERN HEMLOCK	62	44	33	18	33	3	5	3		1			573	202
	2. COASTAL CE-P-H	6	3	2	3	2								40	16
	3. MOUNTAIN HEMLOCK	4	7	9	5	5	4		1	2	1			150	38
	4. ALPINE TUNDRA														
BEDROCK FORMATIONS	1. MASSET-TM	26	23	12	12	19	2	3	3		2			328	102
	2. SKIDGATE-KS														
	3. HONNA-KHO	1	1	1		1								11	4
	4. HAIDA-KHA	9	4	7		4	1	1	1					79	27
	5. LONGARM-KL	2	3											8	5
	6. YAKOUN-JY	17	6	9	2	1				2				87	37
	7. MAUDE-JM														
	8. KUNGA-JKU	1	2	1	1	1	1							23	7
	9. KARMUTSEN-PKA	5	8	6	2	8	2							99	31
	10. PLUTONS-POST.T.-KTP	10	7	8	9	6	1	1						127	42
	11. PLUTONS-SYN.T.-JS	1												1	1
	12. METAMORPHIC-JSN														
LAND USE	1. FORESTED	51	44	23	22	26	5	2	2	1	1			505	177
	2. LOGGING	17	9	19	3	12	2	3	2	1	1			232	69
	3. ROAD	4	1	2	1	2								26	10
	4. MINING														
ELEVATION ASL	1. <500FT ASL	8	6	1	1	1								32	17
	2. 500FT-1000FT ASL	20	13	12	6	11	2	1			1			190	66
	3. 1000FT-1500FT ASL	22	17	15	7	10	1	2	3					223	77
	4. 1500FT-2000FT ASL	13	9	7	5	10		1						129	45
	5. 2000FT-2500FT ASL	8	7	6	5	6	4	1		1				130	38
	6. 2500FT-3000FT ASL	1	2	2	2	2			1	1	1			56	12
	7. >3000FT ASL			1										3	1
SLOPE STEEPNESS CLASSES	1. 0-30%														
	2. 31%-60%	29	13	10	2	6					1			133	61
	3. 61%-90%	41	39	29	21	28	7	5	4	2	1			567	177
	4. 91%-120%	2	2	5	3	6								63	18
	5. >120%														
SLOPE ASPECT	1. WEST	6	1	1	1	1								20	10
	2. NORTHWEST	10	3	4	1	2	1	1						55	22
	3. NORTH	4	4	2	2	3								41	15
	4. NORTHEAST	16	9	7	6	15	1	2	3	1	1			217	61
	5. EAST	3	5	2	4	1	1	2						60	18
	6. SOUTHEAST	20	11	12	6	9	3		1	1				182	63
	7. SOUTH	2	5	1	1	4					1			49	14
	8. SOUTHWEST	11	16	15	5	5	1							139	53
POSITION ON SLOPE	1. LOWER	23	16	7	3	4	2							120	55
	2. MIDDLE	24	14	14	11	24	1	1	1		1			289	91
	3. UPPER	25	24	23	12	12	4	4	3	2	1			354	110

FIGURE 13. One-km^2 grid cells of a single NTS map summarized by frequencies and landscape characteristics.

4 RESULTS AND DISCUSSION

4.1 Estimated Number of Slope Failures

A total of 8328 slope failure forms were identified from the 1979-1980 small scale aerial photographs and presented on 1:50 000 scale topographic maps. This figure includes mainly the slope failures large enough to be detected at that scale is thus a conservative estimate.

In addition to the resolution of photographic scale, other factors such as heavy forest cover and shadow areas (common in mountainous terrain) made it difficult to identify all slope failures. To estimate how many slope failures were missed with the medium scale photography, several stream basins were examined on 1:10 000 scale panchromatic and color-infrared photography flown in 1981 with 300 mm focal length cameras, and on 1:12 000 scale color-negative prints obtained in 1982 with a standard 152 mm camera. The resolution of medium scale photography was considerably better, particularly the 1:10,000 scale photography (Figure 14). The color-infrared and normal color photography was also superior to the conventional black-and-white for identification of small failures, old revegetated landslides, and debris torrents. On average, the number of slope failures identified on the medium scale photographs was from 17 to 33% higher (average about 27%) than the number recorded from the 1:50 000 scale photographs. In addition to several new landslides that occurred between 1979 and 1982, the failures that were usually missed on the small scale photography included numerous slides less than 100 m long (less than 2 mm on photograph), small debris flows associated with the V-notch gullies, soil slumps along logging roads, and portions of torrented streams obscured by the vegetation (Figures 14, 15, 16, and 18). A 27% correction, derived from the analysis of six watersheds on the medium scale (1:10 000 and 1:12 000) photography, increased the total estimated number of failures to over 10 500.

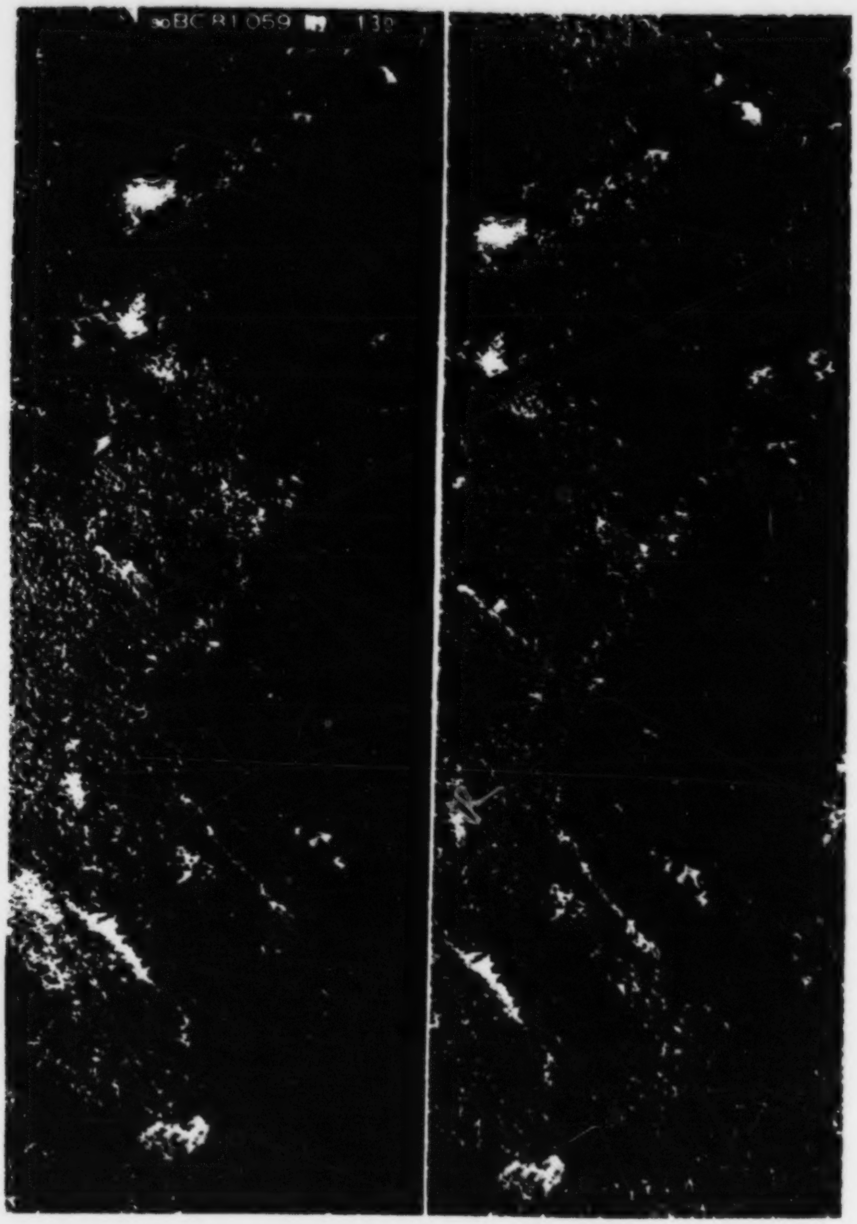

FIGURE 14. Example of medium scale (1:10 000) aerial photography taken with a 300 mm lens camera (BC 81 059, Nos. 130-131). It permits discrimination of much more detail than the 1:50 000 scale, e.g., small slope failures (a), older slides or avalanche tracks (b), fully or partly revegetated scars (c), and torrented segments of streams (d). Location: 103-F/8W (Yakoun Lake).

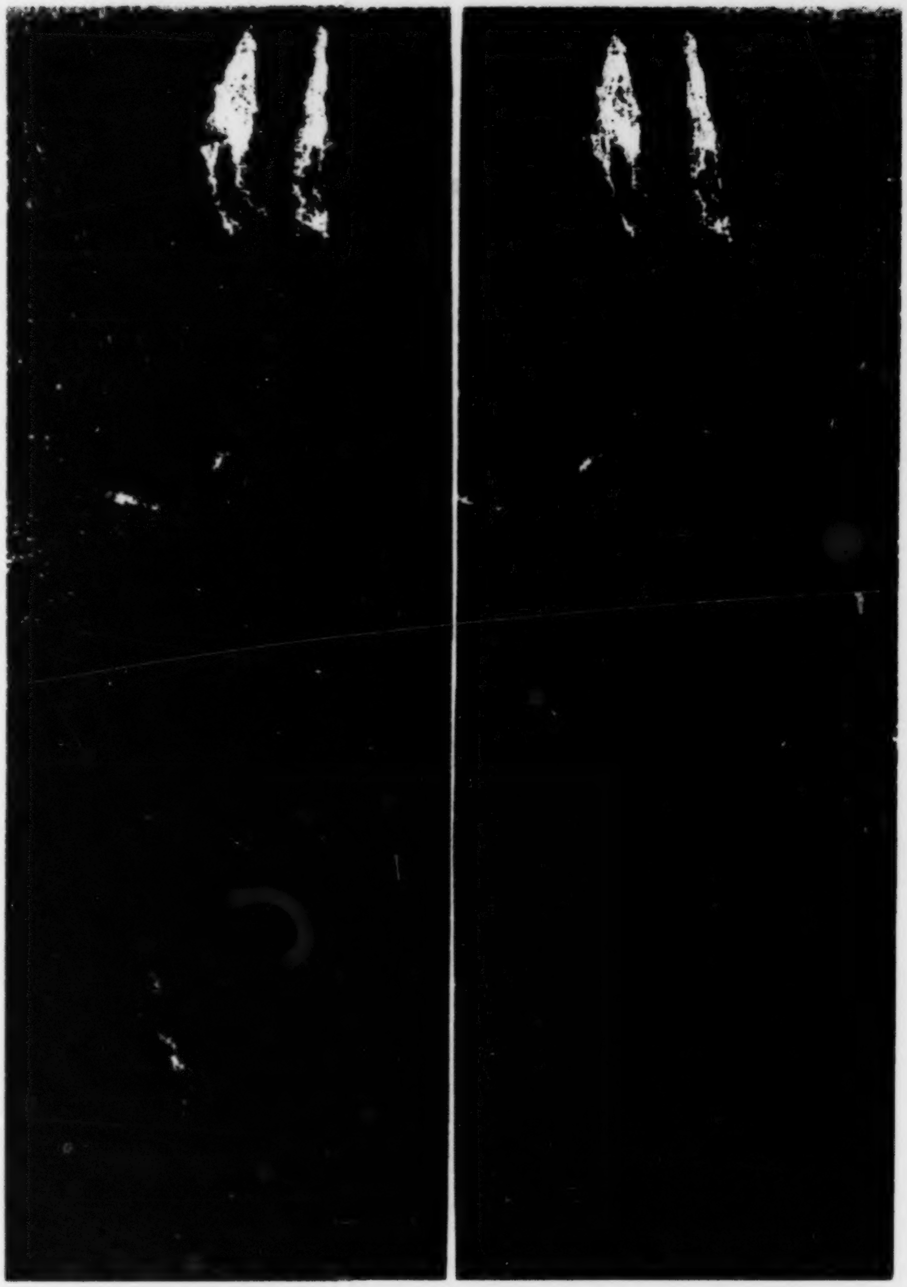

FIGURE 15. Series of debris slides and gully erosion on forested slopes. Erosion in steep V-notch gullies (a) extends into stream channel; debris slides at b, c, and d are partly revegetated. A stereogram from 1982 medium scale (1:12 000) color negative (BCC 325, Nos. 41-42). Location: NTS 103-B/6W (Burnaby Island).

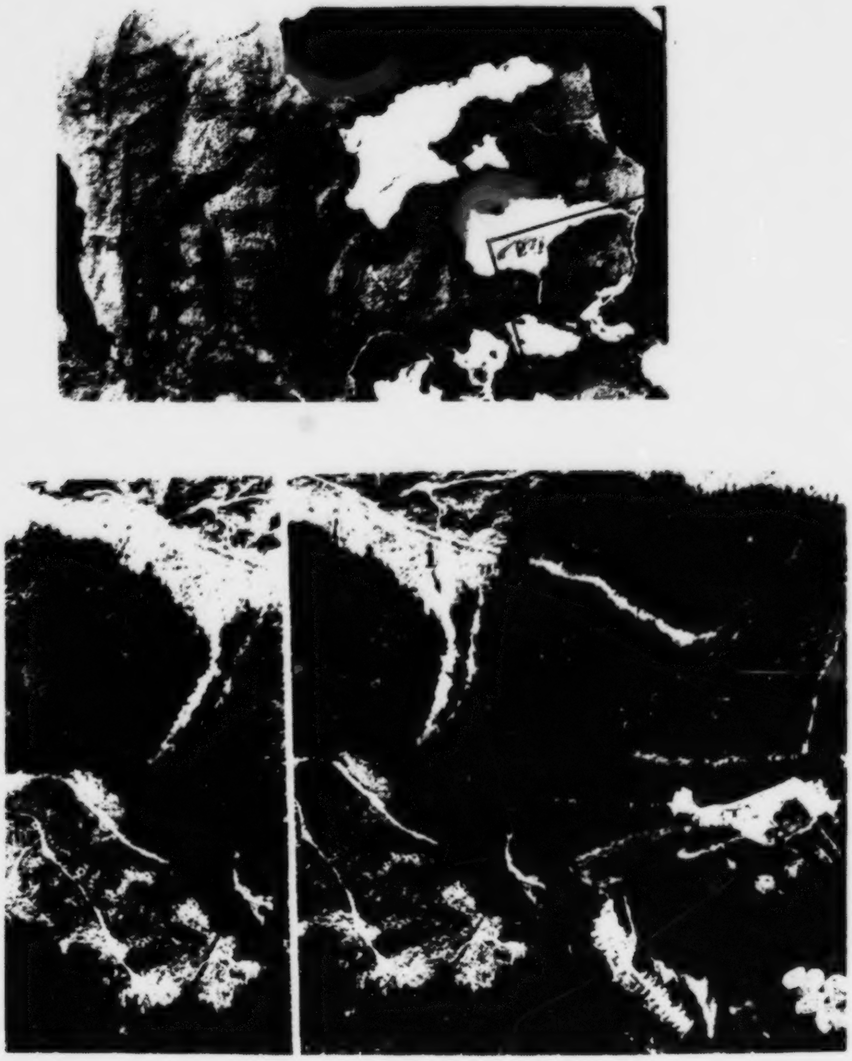

FIGURE 16. Small debris slides initiated in a clearcut area (Powrico Bay on Lyell Island, NTS 103-B/12E). Two narrow slides (S) with the initiation points (i) and debris deposition (d) are quite distinct on this stereogram prepared from 1982 color negative 1:12,000 scale photographs (BCC 325, Nos. 14-15). The same slope failures on 1:50 000 scale (portion of print A25535, No. 4, shown below) may be overlooked because of their regular shape resembling an extension of a logging trail.

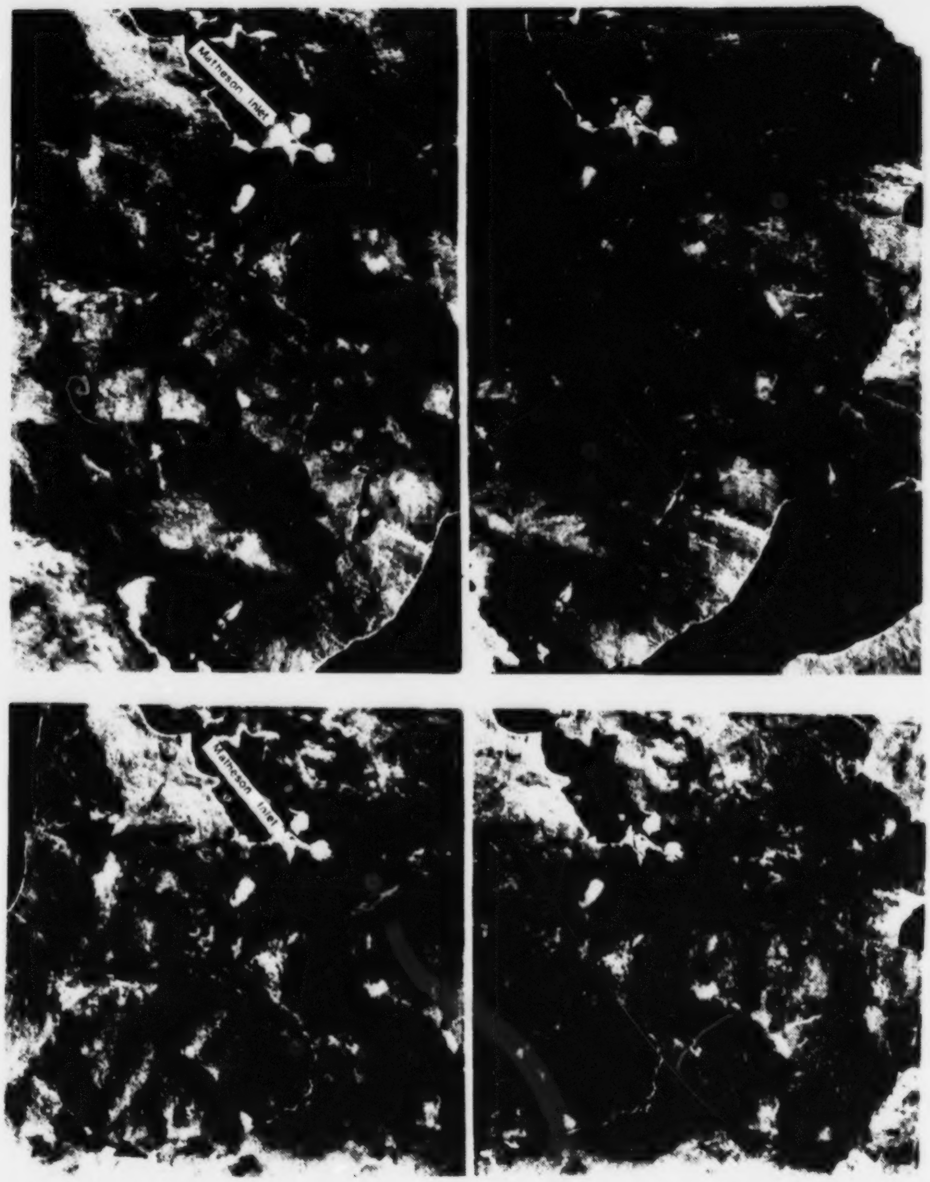

FIGURE 17. Debris torrents and debris slides in NTS 103-B/6W (Matheson Inlet). Stereograms from two adjoining flight lines of 1:50 000 scale photography flown in 1979 (below) and 1980 (above), showing several debris slides and torrented streams. A 2 km long torrent (T1) is clearly visible on the 1980 photograph (A 25535, Nos. 7-8) but not on the lateral overlap of the same area flown in 1979 (A 25291, Nos. 97-98).

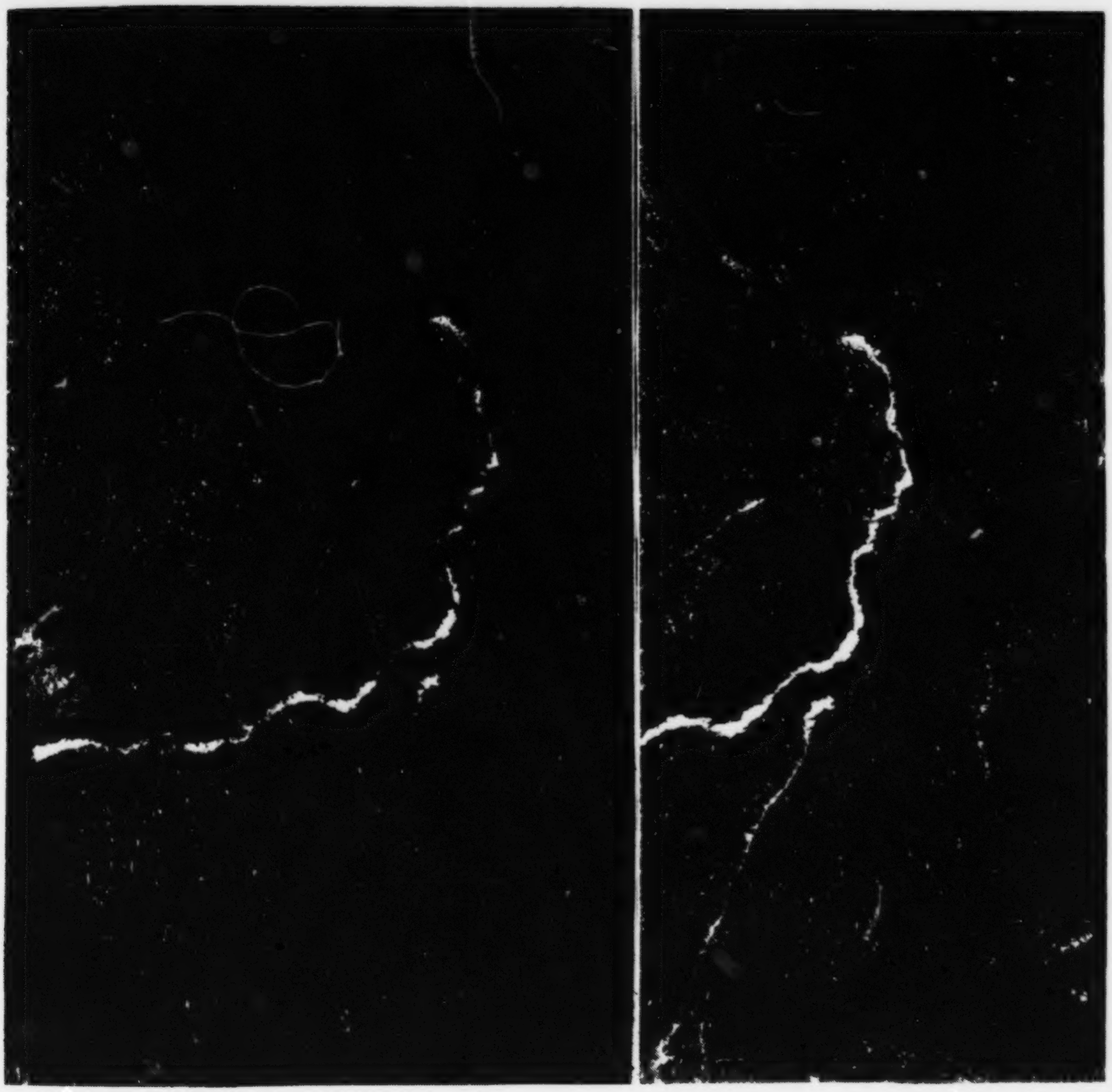

FIGURE 18. Debris torrents. A stereogram from 1982 color negative film, scale 1:12 000 (BCC 325, Nos. 30-31). T1 and T2 are the same torrented streams shown in Figure 17. Debris accumulation is clearly visible at D.

4.1.1 Slope failure type and size

The size of individual slope movements varies with the type of process. Most debris slides and debris flows were small and their average lengths, observed on the 1:50 000 scale photographs, ranged from less than 100-600 m. Debris torrents were generally longer, ranging from 2000 to 4000 m.

The 1981-1982 field survey of 45 debris slides in 18 watersheds (Smith et al. 1982) indicated that the average length and width of these 45 failures was 506 m and 47 m, respectively. A minimum length of 84 m was recorded for a debris slide, SA-1 in the Sachs Creek area in NTS 103-G/4W; and a maximum of 2400 m for a debris torrent, SB-3 in South Bay watershed, NTS 103-F/1E. The minimum and maximum widths ranged from 10 m to over 90 m. The average size of these failures was estimated to be over 2 ha.

To provide additional data, the lengths of all slope failures were measured on 1:50 000 scale topographic maps and grouped into four classes: up to 5 mm on the map (up to 250 m long), from 5 mm to 1 cm (250-500 m), 1-2 cm (500-1000 m), and more than 2 cm on the map (longer than 1000 m).

The summary of these measurements indicated that out of the total of 8328 slope failures more than one-half (4539, or 54.7%, mainly debris slides and debris flows) had an average length of 250 m or less. Almost one-third of the failures (2659, or 31.9%) were between 250 and 500 m long. About 12% (1010 slides) ranged from 500 to 1000 m, and the remaining 120 failures (1.2%) were longer than 1000 m, and included mainly prominent debris torrents -- some over 2500 m long -- as illustrated in Figure 17.

The estimated average length of all slope failures was about 340 m. When the average 47 m width derived from the field survey data (Smith et al. 1982) was applied, the size of denuded area occupied by a single slide was about 1.6 ha, or 14 145 ha (141.45 km^2) for the 8328 slope failures recorded in this survey.

This represents more than 1.4% of the total land area of the Queen Charlotte Islands.

4.1.2 Slope failure intensity

The intensity of landslide activity was expressed initially as a number of failures per 1 km^2 of the affected area of the drainage basins (Figures 5 and 7). Because the boundaries of these "active" drainage units were often arbitrary, it was decided to compile the frequency data by the number of slope failure initiation points inside the 1-km^2 UTM grid cells.

Table 1 shows the occurrence and distribution of 8328 slope failures within corresponding 3153 UTM cells listed by individual NTS 1:50 000 map sheets. No landslide activity was recorded in the 10 map sheets (103-F/16 E and W, -G/5W, -G/13E and W, -J/4E and W, -K/1E and W, and -K/2E), and only 2 and 7 slope failures in map sheets -F/9E and -G/12W, respectively. These 12 NTS map sheets comprise about one-quarter (25.5%, or 2536 km^2) of the total land area of the Islands and largely represent the Queen Charlotte Lowlands. The remaining 31 map sheets, covering about three-quarters (74.5%), or 7 410 km^2 of the Queen Charlotte Islands land area, represent areas subjected to significant mass wasting processes; and fall within the Skidegate Plateau and Queen Charlotte Ranges. The intensity of these processes in individual map sheets areas is indicated by the average number of failures per square kilometer of the land area and UTM cells, and also by the proportion of the "active" area, expressed by the number of UTM cells in relation to the total map sheet area.

In the NTS map sheet 103-B/12W (Darwin Sound), for example, there were 554 slope failures occurring in 189 one-km^2 UTM cells. The estimated area of this map sheet (Table 1) is 275.92 km^2, and 68.5% of it (189 UTM cells) was subjected to active mass wasting. Average number of slope failures per 1 km^2 of the map sheet land area was 2.01, and 2.93 failures per one UTM cell (554:275.92, and 554:189). The average frequency for the entire Queen Charlotte

TABLE 1. Summary of slope failures by NTS map sheets

NTS MAP SHEET	Est. Land Area km^2	% Total Area	No. of UTM Grid Cells	% Land Area	% Total Cells	Number of Failures	% of Total	Ave. No. of failures per km^2	
								Total Map Sheet Area	UTM Cells
103-B2W Lyman Point	19.06	0.2	9	47.4	0.3	18	0.2	0.94	2.00
" B/3E Kungit Island +102-O/14E	313.14	3.1	121	38.6	3.8	276	3.3	0.88	2.28
103-B/3W Kungit Island	82.87	0.8	38	45.8	1.2	73	0.9	0.88	1.92
" B/5E Gowgaya Bay	137.96	1.4	88	63.3	2.8	229	2.7	1.66	2.60
" B/6E Jedway	66.86	0.7	35	52.3	1.1	71	0.8	1.06	2.03
" B/6W "	226.09	2.3	107	47.3	3.4	233	2.8	1.03	2.18
" B/11W Ramsay Island	64.84	0.6	25	38.5	0.8	51	0.6	0.79	2.04
" B/12E Darwin Sound	255.72	2.6	105	41.1	3.3	191	2.3	0.75	1.82
" B/12W " "	275.92	2.8	189	68.5	6.0	554	6.6	2.01	2.93
" B/13E Louise Island	159.66	1.6	88	55.1	2.8	211	2.5	1.32	2.40
" B/13W " "	267.45	2.7	255	95.3	8.1	825	10.6	3.31	3.47
103-C/9E Tasu Head	44.27	0.4	22	49.7	0.7	46	0.5	1.04	2.09
" C/16E Moore Channel	358.23	3.6	243	67.8	7.7	491	5.9	1.37	2.02
" C/16W " "	65.05	0.6	55	84.5	1.7	231	2.8	3.55	4.20
103-F/1E Skidegate Channel	350.85	3.5	165	47.0	5.2	527	6.3	1.50	3.19
" F/1W " "	366.03	3.7	250	68.3	7.9	794	9.5	2.17	3.18
" F/2E Cartwright Sound	86.41	0.9	69	79.8	2.2	182	2.2	2.12	2.64
" F/7E Rennell Sound	268.18	2.7	190	70.9	6.0	634	7.6	2.36	3.34
" F/7W " "	26.22	0.3	17	64.8	0.5	60	0.7	2.31	3.53
" F/8E Yakoun Lake	474.98	4.8	36	7.6	1.1	61	0.7	0.13	1.69
" F/8W " "	461.68	4.6	190	41.1	6.0	465	5.6	1.01	2.45
" F/9E Port Clements	433.00	4.3	1	–	–	2	–	–	–
" F/9W " "	315.39	3.2	64	20.3	2.0	132	1.6	0.42	2.06
" F/10E Awun Lake	401.83	4.0	199	49.5	6.3	506	6.0	1.26	2.54
" F/10W " "	355.23	3.6	169	47.6	5.3	489	5.9	1.38	2.89
" F/14E Frederick Island	211.23	2.1	81	38.4	2.6	202	2.4	0.96	2.49
" F/15E Naden River	412.65	4.1	55	13.3	1.7	88	1.0	0.21	1.60
" F/15W " "	446.52	4.5	161	36.1	5.1	315	3.8	0.71	1.96
" F/16E Masset Sound	401.85	4.0	–	–	–	–	–	–	–
" F/16W " "	438.38	4.4	–	–	–	–	–	–	–
103-G/4E Cumshewa	77.84	0.8	11	14.1	0.3	18	0.2	0.23	1.64
" G/4W "	334.50	3.4	45	13.4	1.4	115	1.4	0.34	2.55
" G/5W Lawnhill	104.40	1.0	–	–	–	–	–	–	–
" G/12W Tlell	149.73	1.5	2	–	–	7	–	–	–
" G/13E Eagle Hill	16.49	0.2	–	–	–	–	–	–	–
" G/13W " "	421.37	4.2	–	–	–	–	–	–	–
103-J/4E Tow Hill	57.76	0.6	–	–	–	–	–	–	–
" J/4W " "	97.90	1.0	–	–	–	–	–	–	–
103-K/1E Masset	51.18	0.5	–	–	–	–	–	–	–
" K/1W "	175.81	1.8	–	–	–	–	–	–	–
" K/2E Jalun River	188.58	1.9	–	–	–	–	–	–	–
" K/2W " "	275.08	2.8	56	20.4	1.8	129	1.5	0.47	2.30
" K/3E Langara	107.73	1.1	10	9.3	0.3	16	0.2	0.15	1.60
TOTAL (43-½ Map Sheets)	9 945.92	100.0	3 153	31.7	100.0	8 328	100.0	0.84	2.64

TABLE 2. Intensity of slope failures by UTM grid cells

Intensity Classes	Frequency (No. of failures/km^2)	Area in km^2 (No. of UTM Grid Cells)	% of all "active" UTM Cells	Number of Slope Failures	% of all failures
I MODERATE	1	1 109	35.2	1 109	13.3
	2	740	23.8	1 498	18.0
	3	502	15.9	1 506	18.1
1 - 3 failures per km^2		2 360	74.9	4 113	49.4
II SEVERE	4	331	10.5	1 324	15.9
	5	205	6.5	1 025	12.3
	6	101	3.2	606	7.3
	7	80	2.5	560	6.7
4 - 7 failures per km^2		717	22.7	3 515	42.2
III EXTREME	8	32	1.0	256	3.1
	9	22	0.7	198	2.4
	10	11	0.3	110	1.3
	11+	11	0.3	136	1.6
More than 8 failures per km^2		76	2.4	700	8.4
ALL INTENSITY CLASSES		3 153	100.0	8 328	100.0

Islands land area (43 NTS map sheets), shown at the bottom of Table 1, was 0.84 failures per square kilometer (8328 failures: 9945.92 km^2 total land area), while average frequency by UTM cells was 2.64 failures per 1-km^2 cell (8328 failures:3153 UTM cells).

The "active" landslide area (3153 UTM cells) occupies about 31.7% of the total land area of the Islands.

A listing of UTM cells summarized by frequencies and corresponding number of failures is presented in Table 2. It shows the proportion of UTM cells in 11 frequency classes (from 1 failure per square kilometer to more than 11). The UTM cells with a single slope failure, for example, embraced over 35% of all cells; two failures per square kilometer occur in almost one-quarter of the cells (23.8% or 740 cells), and 15.9% (502 cells) had three slope failures per cell. The number of UTM cells rapidly decreased after frequency class "4", and only 11 one-km^2 cells were recorded with frequencies 11, 12, 13, 14, and 18. They were listed as a combined class "11+".

For the presentation of an overall overview of mass wasting processes on the Queen Charlotte Islands, the above frequencies in UTM cells were condensed into three intensity classes: moderate, severe, and extreme, as given in Table 2 and shown in Figures 19 and 22.

Class 1 (Moderate) consisted of frequencies 1, 2, and 3 per square kilometer and included almost three-quarters (74.9%, or 2360 km^2) of all "active" UTM cells. About one-half of all slope failures (4113) were in this intensity class. Average frequency was 1.74 slides per square kilometer.

Class 2 (Severe) consisted of UTM cells having 4, 5, 6, and 7 slope failures per square kilometer, with an average of 7.9. A total of 717 UTM cells (22.7% of all cells) and 3515 slope failures (42.2% of all slope failures) were in this category.

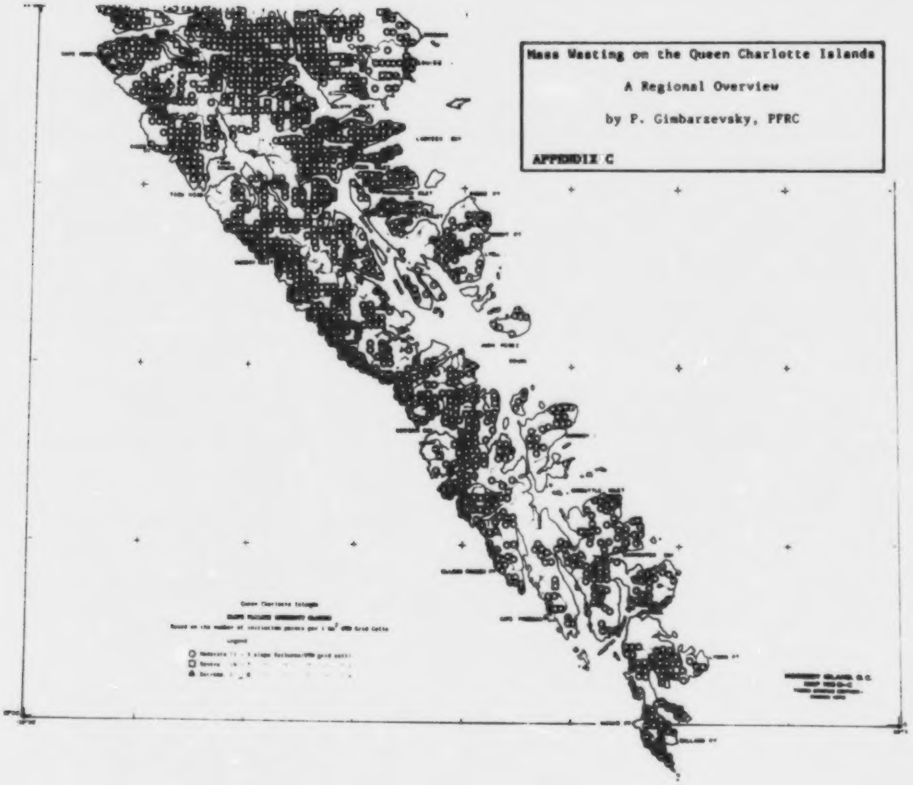
Mass Wasting on the Queen Charlotte Islands
A Regional Overview
by P. Gimbarzevsky, PFRC
APPENDIX C

FIGURE 19. Slope failure intensity classes by one-km^2 UTM grid cells - overview map of Moresby Island, B.C. Map 103-B-C (reduced from 1:250 000 scale, original in map pocket).

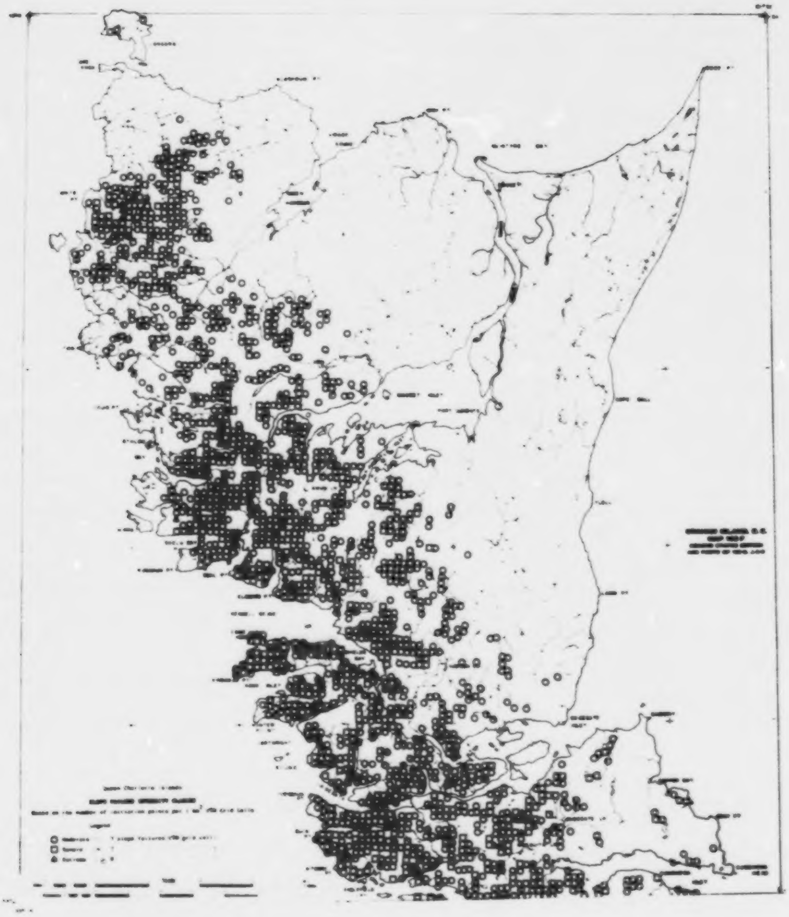

FIGURE 20. Slope failure intensity classes by one-km^2 UTM grid cells - overview map of Graham Island, B.C. Map 103F (reduced from 1:250 000 scale, original in map pocket).

QUEEN CHARLOTTE ISLANDS - ANALYSIS OF SLOPE FAILURE FREQUENCIES
BY UTM CELLS AND LANDSCAPE CHARACTERISTICS NTS 103-B,12E

103-B/12E

LANDSCAPE CHARACTERISTICS		NUMBER OF 1 KM**2 UTM CELLS CONTAINING N LANDSLIDES (N=1 TO 11+)											TOTAL	
		1	2	3	4	5	6	7	8	9	10	11+	SLIDES	CELLS
MAJOR PHYSIOGRAPHIC SUBDIVISIONS	1. SEDIMENTARY-NW													
	2. MIXED VOLCANICS-NW													
	3. PLUTONS-W	25	9	4	1					1			68	40
	4. PLUTONS-E													
	5. MIXED VOLCANICS-SW	4	2	1									11	7
	6. MIXED VOLCANICS-NE													
	7. MIXED SEDIMENTARY-E													
	8. MIXED VOLCANICS-SE	26	18	10	2	1		1					112	58
	9. LIMESTONE													
	10. SED. AND GLACIAL DEPOSITS													
PRECIPITATION ZONES	1. LOW (1260-1370 MM/YR)													
	2. MODERATE (1665-1765 MM/YR)													
	3. HIGH (2035-2225 MM/YR)	28	18	10	2	1		1					114	60
	4. EXTREME (3665-3775 MM/YR)	27	11	5	1					1			77	45
BIO-GEOCLIMATIC ZONES	1. COASTAL WESTERN HEMLOCK	55	29	15	3	1		1		1			191	105
	2. COASTAL CE-P-M													
	3. MOUNTAIN HEMLOCK													
	4. ALPINE TUNDRA													
BEDROCK FORMATIONS	1. MASSET-TM	15	13	3	2	1							63	34
	2. SKIDEGATE-KS													
	3. HONNA-KHO													
	4. HAIDA-KHA													
	5. LONGARM-KL			1									3	1
	6. YAKOUN-JY	1	1	2				1					16	5
	7. MAUDE-JM													
	8. KUNGA-JKU													
	9. KARMUTSEN-RKA	12	5	3									31	20
	10. PLUTONS-POST.T.-KTP	6	2	3									19	11
	11. PLUTONS-SYN.T.-JS	20	8	3	1					1			58	33
	12. METAMORPHIC-JSN	1											1	1
LAND USE	1. FORESTED	53	28	12	3			1		1			173	98
	2. LOGGING	2	1	3		1							18	7
	3. ROAD													
	4. MINING													
ELEVATION ASL	1. <500FT ASL	7	4	1									18	12
	2. 500FT-1000FT ASL	22	20	7	2					1			100	52
	3. 1000FT-1500FT ASL	17	3	3	1	1		1					48	26
	4. 1500FT-2000FT ASL	7	1	4									21	12
	5. 2000FT-2500FT ASL	2	1										4	3
	6. 2500FT-3000FT ASL													
	7. >3000FT ASL													
SLOPE STEEPNESS CLASSES	1. 0-30%													
	2. 31%-60%	17	9	2									41	28
	3. 61%-90%	37	19	13	3	1		1		1			147	75
	4. 91%-120%	1	1										3	2
	5. >120%													
SLOPE ASPECT	1. WEST	1		1				1					11	3
	2. NORTHWEST	4	3		2								18	9
	3. NORTH	1	1	1									6	3
	4. NORTHEAST	10	5	2		1							31	18
	5. EAST	2	2										6	4
	6. SOUTHEAST	19	9	6									55	34
	7. SOUTH	3	3	3									18	9
	8. SOUTHWEST	15	6	2	1					1			46	25
POSITION ON SLOPE	1. LOWER	11											11	11
	2. MIDDLE	16	16	7	3					1			90	43
	3. UPPER	28	13	8		1		1					90	51

FIGURE 21. A summary of all UTM grid cells in 33 NTS map sheets classified by landscape characterisitics and frequencies.

Class 3 (Extreme) consisted of UTM cells with frequencies 8, 9, 10, and 11⁺ failures per square kilometer. Average frequency was 9.2. This high concentration of slope failures class included 76 UTM cells (2.4% of total) with 700 failures (8.4% of the total number of failures).

A general overview of the intensity of slope movement processes for the entire study area was presented as a "Slope Intensity Classes" maps at the scale of 1:250 000 (Appendix 2), where the 3153 one-km^2 UTM cells were classified on the basis of the actual number of landslide initiation points, and presented within one of the three intensity classes.

Figure 19 and 20 are photographic reductions of the original maps compiled at the scale of 1:250 000 (originals in map pocket).

4.2 Analysis of UTM Cells by Landscape Characteristics

The summary of landslide survey data presented in Figure 21, displays the "active" areas as one-km^2 UTM cells, classified by their dominant landscape characteristics, and grouped by the number of slope failure initiation points they contain, into the 11 slope failure frequency classes. The 3153 UTM cells are listed by their landscape characteristics and frequencies. The totals for the number of slides and UTM cells in each subdivision of the nine "landscape characteristics" types are shown in the last two columns of the Summary. The total number of slides for frequency class was obtained by multiplying the number of UTM cells by the corresponding frequency, while the total of UTM cells is simply the sum of all cells listed under the frequencies of a particular landscape characteristics subdivision. For example:

The first line in the Summary (Figure 21) shows for the Regional Area 1 (Sedimentary NW, or Langara Plain) a total of 28 slides and 15 UTM cells. There are six cells with one failure per cell, six cells with two, two cells with three, and one cell with four -- or a total 28 slides and 15 UTM cells.

The individual "Total" listed in the last two columns for each of the 10 Regional Areas adds up to 8338 slides and 3153 UTM cells.

The proportion of the number of failures and UTM cells within a particular subdivision may be used as a general indicator of landslide activity. To correlate the occurrence and frequency of slope failures with basic landscape characteristics, the 3153 UTM cells were subjected to a systematic analysis. The results are tabulated in a set of tables and diagrams, described in the following sections.

4.2.1 Physiography

Classification of UTM cells by the physiography was based on a map of the Queen Charlotte Islands compiled by Sutherland Brown (1968), modified by Chamberlain and Karanka[2], and revised in 1984 by Beaven (Figure 23). This map shows three major physiographic subdivisions (Queen Charlotte Ranges, Skidegate Plateau, and Queen Charlotte Lowland), and 10 regional areas "characterised by similar geologic, climatic and relief factors".[3]

For the classification of UTM cells by the regional physiographic areas the following numeric codes were used: (The names of 10 regional physiographic areas shown in brackets have been suggested by the author of this report.)

Code 1. Sedimentary NW (Langara Plain)
Code 2. Mixed Volcanics NW (Graham Ranges)
Code 3. Plutons W (San Christoval Mountains)
Code 4. Plutons E (Kermode Mountains)
Code 5. Mixed Volcanics SW (Moresby Ranges)
Code 6. Mixed Volcanics NW (Skidegate Plain)
Code 7. Mixed Sedimentary E (Cumshewa Uplands)

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[2] Chamberlain, T. and Karanka. 1984. FFIP (unpublished).
[3] Ibid.

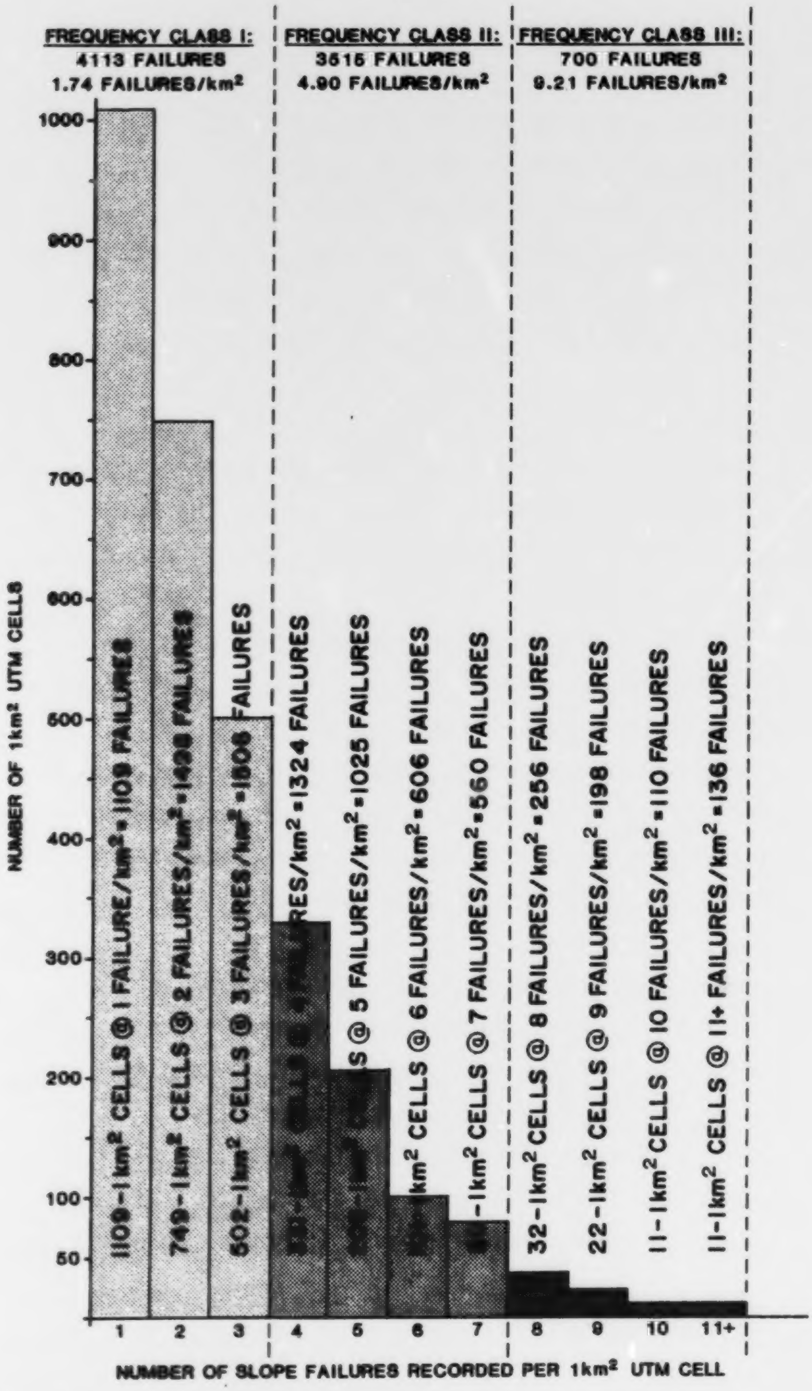

FIGURE 22. A diagram of slope failure frequency classes.

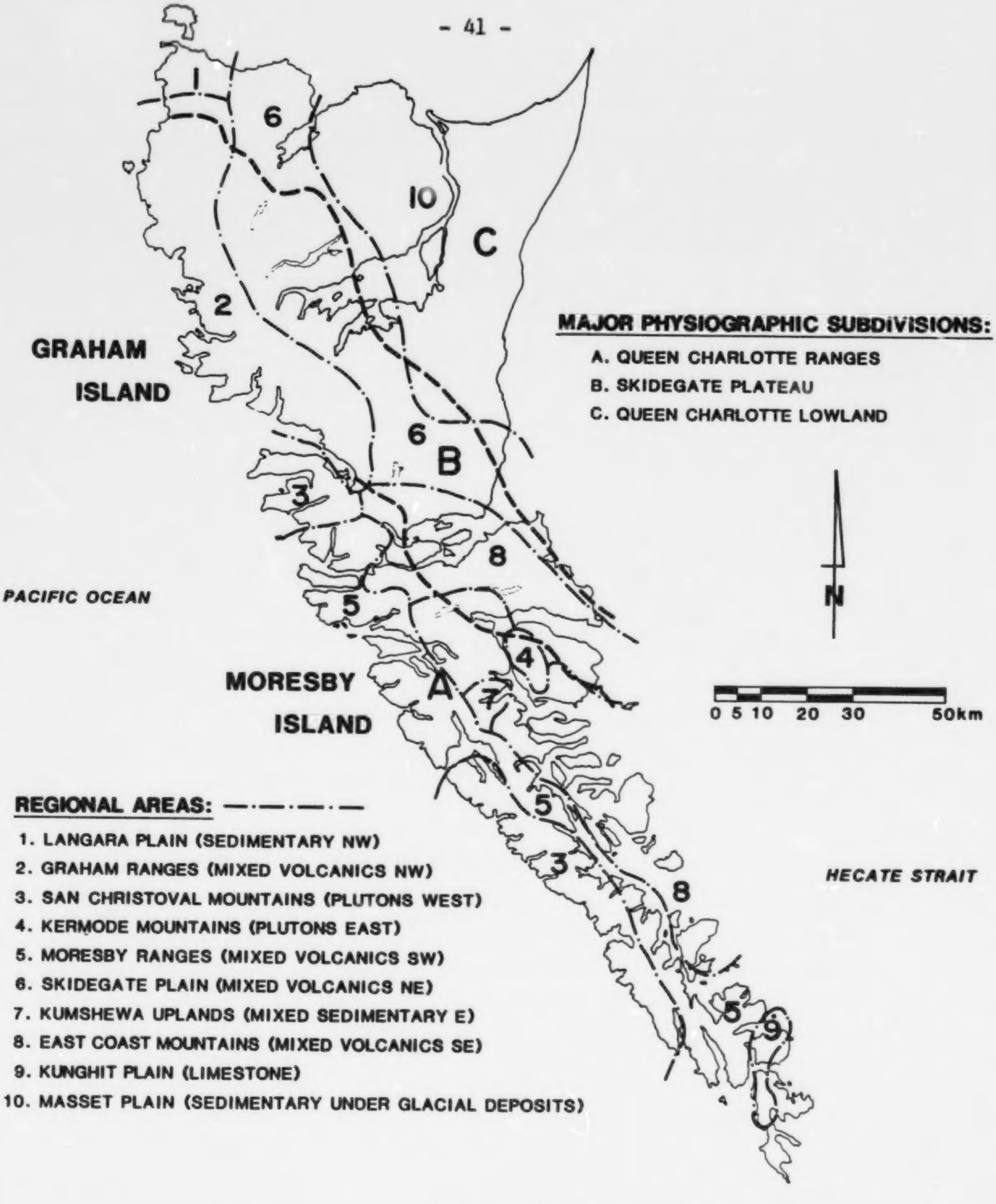
1
6
10
C
2
GRAHAM
ISLAND
MAJOR PHYSIOGRAPHIC SUBDIVISIONS:
A. QUEEN CHARLOTTE RANGES
B. SKIDEGATE PLATEAU
C. QUEEN CHARLOTTE LOWLAND
6
B
3
8
N
PACIFIC OCEAN
5
4
MORESBY
ISLAND
A
7
0 5 10 20 30 50km
5
REGIONAL AREAS: —·—·—·—
1. LANGARA PLAIN (SEDIMENTARY NW)
2. GRAHAM RANGES (MIXED VOLCANICS NW)
3. SAN CHRISTOVAL MOUNTAINS (PLUTONS WEST)
4. KERMODE MOUNTAINS (PLUTONS EAST)
5. MORESBY RANGES (MIXED VOLCANICS SW)
6. SKIDEGATE PLAIN (MIXED VOLCANICS NE)
7. KUMSHEWA UPLANDS (MIXED SEDIMENTARY E)
8. EAST COAST MOUNTAINS (MIXED VOLCANICS SE)
9. KUNGHIT PLAIN (LIMESTONE)
10. MASSET PLAIN (SEDIMENTARY UNDER GLACIAL DEPOSITS)
3
8
HECATE STRAIT
5
9

FIGURE 23. Major physiographic subdivisions and regional areas. (Sutherland Brown 1968, Chamberlain and Karanka 1981)

Code 8. Mixed Volcanics SE (East Coast Mountains)
Code 9. Limestone (Kunghit Plain)
Code 10. Sedimentary under glacial deposits (Masset Plain).

Figure 24 and Table 3 illustrate the occurrence of slope failures in three Major Physiographic Subdivisions A, B, and C, and 10 regional areas. The most "active" areas are within the Queen Charlotte Ranges physiographic subdivision (A), which includes five regional areas -- 3, 4, 5, 8, and 9 -- with an estimated area of 2744 km^2. While this subdivision accounts for 27.6% of the total land area of the Queen Charlotte Islands, about 58% of all slope failures occur in 1776 UTM cells (56.3% of all UTM cells) located within the boundaries of its five regional areas. The most active is the regional area 5 (Moresby Ranges [Mixed Volcanics Southwest]), where 1865 slope failures (22.4% of the failures) were recorded in 679 one-km^2 UTM cells. The estimated size of this regional area of 964 km^2, or about 9.7% of the total land area of the Islands, has almost two failures per square kilometer, and 2.75 failures per UTM cells. The number of UTM cells with slope failures (679 UTM cells) in relation to the total land area (964 km^2) indicates that 70% of the land area in this physiographic unit is subjected to active erosional processes. About 70% of UTM cells in the regional area 5 are in frequency class I (one to three slides per square kilometer), almost one-half (48.8%) in class II (four to seven 4 to 7 slides), and the remaining 2% are in class III (more than eight failures per square kilometer).

Table 3 and Figure 24 provide similar data for all physiographic subdivisions. The Skidegate Plateau (Physiographic Subdivision B), for example, occupies about 46% of the Queen Charlotte Islands land area, where some 42% of all failures occur. The Queen Charlotte Lowland (Physiographic Subdivision C) at the other extreme, has little landslide activity in its two regional areas, which account for more than one-quarter (26.6%) of the total study area, but only for 0.5% of all slope failures.

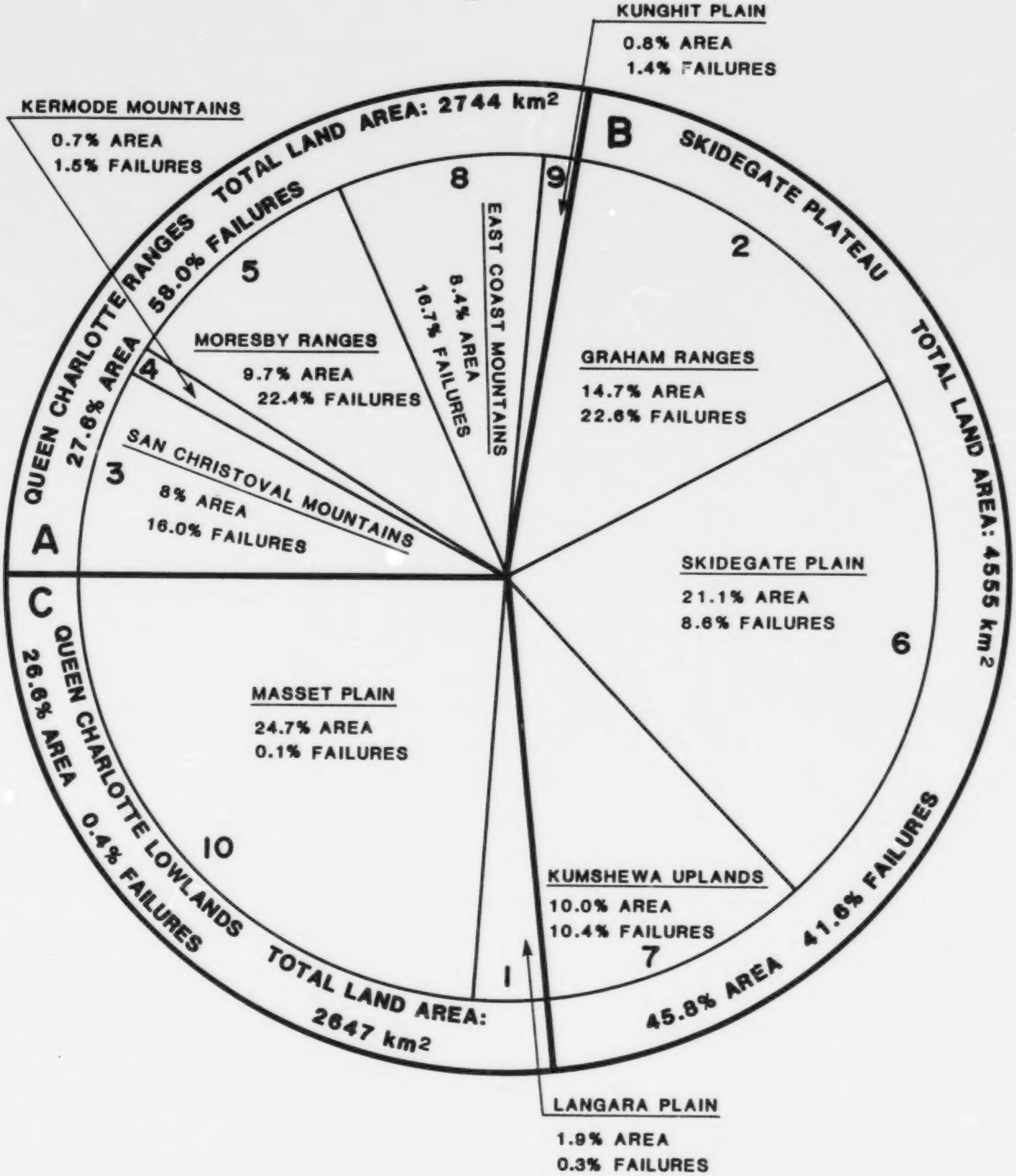

FIGURE 24. Slope failures by major physiographic subdivisions and regional areas.

TABLE 3. Slope failures by 10 regional physiographic areas

Regional Physiographic Area	Major Physiogr. Subdivision	Est. Land Area km^2	% of total Q.C.I. Area	Slope Failures					Ave. slides/km^2		Frequency Classes					
											I (1-3/km^2)		II (4-7/km^2)		III (> 8/km^2)	
				Number of slides	% of all slides	No. of UTM cells	% of all cells	% of land area	Land area	UTM cell	Slides	UTM cells	Slides	UTM cells	Slides	UTM cells
1. Langara Plain	C	186	1.9	28	0.3	15	0.5	8.1	0.15	1.9	24	14	4	1	-	-
2. Graham Ranges	B	1 458	14.7	1 884	22.6	689	21.9	47.2	1.29	2.73	896	509	775	157	209	23
3. San Christoval Mountains	A	796	8.0	1 323	16.0	483	15.3	60.7	1.66	2.74	603	349	603	122	114	12
4. Kermode Mtns.	A	67*	0.7	126	1.5	46	1.5	68.6	1.88	2.74	61	33	56	12	9	1
5. Moresby Ranges	A	964	9.7	1 865	22.4	679	21.5	70.4	1.93	2.75	812	479	911	184	141	16
6. Skidegate Plain	B	2 100	21.1	716	8.6	348	11.0	16.6	0.34	2.06	477	298	210	47	31	3
7. Cumsheva Uplands	B	997	10.0	863	10.4	321	10.2	32.2	0.86	2.69	439	246	324	64	99	11
8. East Coast Mtns.	A	834	8.4	1 393	16.7	511	16.2	61.2	1.67	2.73	701	377	602	124	97	10
9. Kunghit Plain	A	83	0.8	120	1.4	57	1.8	68.7	1.44	2.10	95	52	25	5	-	-
10. Masset Plain	C	2 461	24.7	10	0.1	4	0.1	0.7	0.00	2.50	5	3	5	1		
ALL AREAS (1-10) A+B+C		9 946	100.0	8 328	100.0	3 153	100.0	31.7	0.84	2.64	4 113	2 360	3 515	717	700	76

Major Physiographic Subdivision: A - Queen Charlotte Ranges

B - Skidegate Plateau

C - Queen Charlotte Lowland

4.2.2 Precipitation

Four precipitation zones were delineated on the map "Spatial Variations of Precipitation on the Queen Charlotte Islands".[4]

The boundaries of four of the zones, shown on the map in Figure 25, were based on the mean annual total precipitation:

Zone 1. Mean Annual Total Precipitation 1260-1370 mm/yr
Zone 2. Mean Annual Total Precipitation 1665-1765 mm/yr
Zone 3. Mean Annual Total Precipitation 2035-2225 mm/yr
Zone 4. Mean Annual Total Precipitation 3665-3775 mm/yr

The areal extent of these four precipitation zones used to analyze the landslide data is presented in Table 4. There is no significant landslide activity in precipitation zones 1 and 2, which occupy about 30% of the total land area of the Islands, mainly the Queen Charlotte Lowland and lower slopes of Skidegate Plateau. However, the occurrence of slope failures is considerably higher in zones 3 and 4. The precipitation zone 3, which accounts for 30% of the total land area, has about 32% of all slides; zone 4, comprising almost 40% of total area, has about 68% of all slope failures. These two zones include areas of high elevations and steep slopes of the Queen Charlotte Ranges and Skidegate Plateau physigraphic subdivisions.

Average number of failures per square kilometer in zone 3 is 0.88, and 1.43 in zone 4. The intensity of slope failures in zones 3 and 4 is also indicated by the proportion of "active" 1-km^2 UTM cells and total zone area: in zone 3, slope failures occur in

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[4] Unpublished map compiled from federal Atmospher Environment Service (AES) data derived from eight weather stations; and provincial records (B.C. Ministry of Environment Air Studies Branch, 1980), for 55 short-term stations on the Islands (Hogan, 1985).

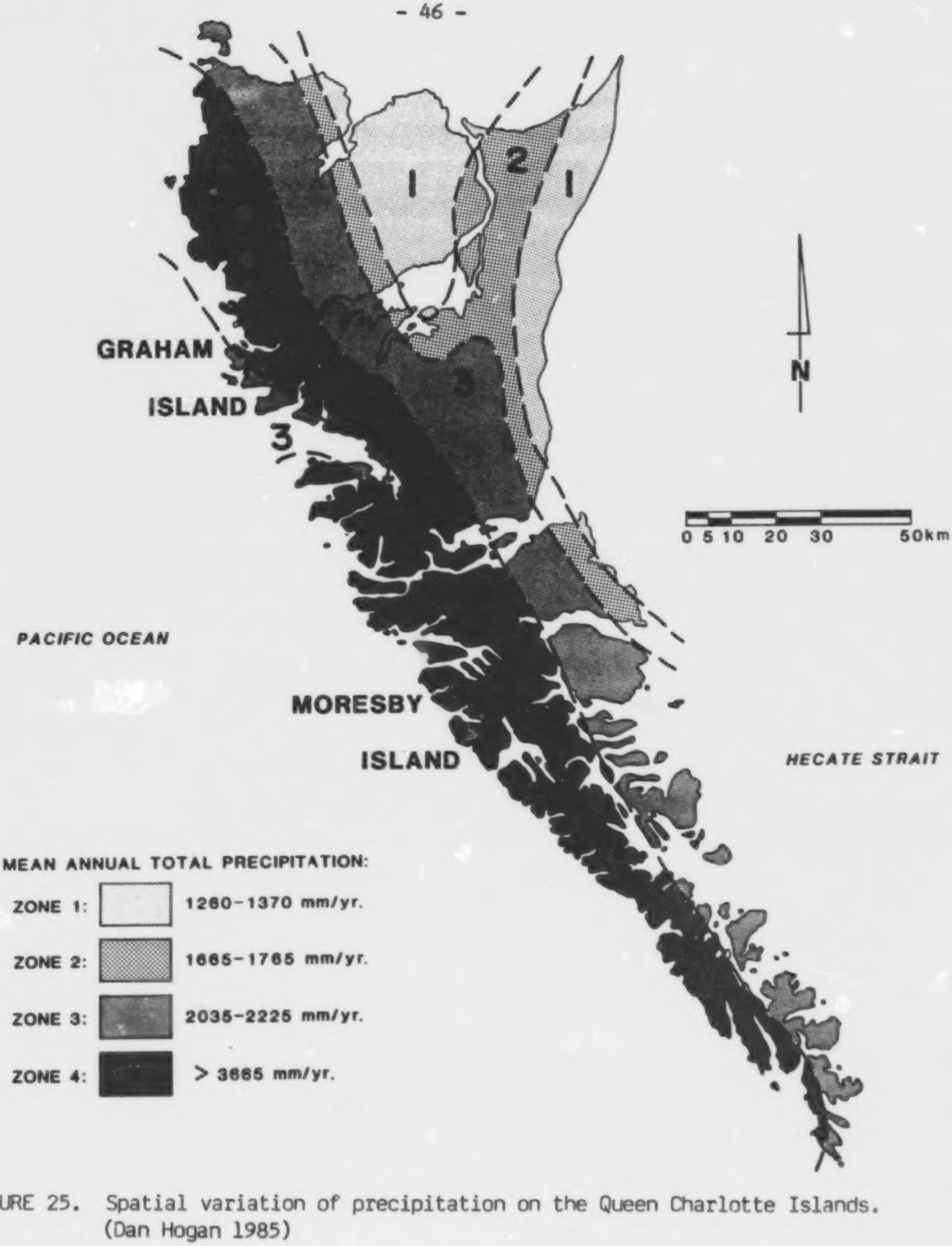
GRAHAM
ISLAND
MORESBY
ISLAND
PACIFIC OCEAN
HECATE STRAIT
1
2
1
3
3
N
0 5 10 20 30 50km
MEAN ANNUAL TOTAL PRECIPITATION:
ZONE 1: 1260-1370 mm/yr.
ZONE 2: 1665-1765 mm/yr.
ZONE 3: 2035-2225 mm/yr.
ZONE 4: > 3665 mm/yr.

FIGURE 25. Spatial variation of precipitation on the Queen Charlotte Islands. (Dan Hogan 1985)

TABLE 4. Slope failures by precipitation zone

Precipitation Zone (Mean annual total) precipitation in mm)	Estimated Zone Area in km^2	% of total Q.C.I. land area	SLOPE FAILURES				AVE. NO. OF FAILURES/KM^2		FREQUENCY CLASSES					
									1-3 slides/km^2		4-7 slides/km^2		> 8 slides/km^2	
			Number of Failures	%	Number of UTM cells	% All $\frac{\text{Cells}}{\text{Zone Area}}$	Total land area	UTM cell	Number of failures	Number of UTM cells	Number of failures	Number of UTM cells	Number of failures	Number of UTM cells
Zone 1: 1260-1370 $\frac{mm}{Y}$	1 581	15.9	7	0.1	2	-	-	-	2	1	5	1	-	-
Zone 2: 1665-1765 $\frac{mm}{Y}$	1 409	14.2	22	0.3	15	$\frac{0.5}{1.1}$	0.01	1.47	22	15	-	-	-	-
Zone 3: 2035-2225 $\frac{mm}{Y}$	2 997	30.1	2 643	31.7	1 134	$\frac{36.0}{37.8}$	0.88	2.33	1 563	922	931	195	149	17
Zone 4: 3665-3775 $\frac{mm}{Y}$	3 959	39.8	5 656	67.9	2 002	$\frac{63.5}{50.6}$	1.43	2.82	2 526	1 422	2 579	521	551	59
Total Q.C.I. area	9 946	100%	8 328	100%	3 153	$\frac{100.0}{31.7}$	0.84	2.64	4 113	2 360	3 515	717	700	76

1134 UTM cells (about 38% of the zone area), while over 50% of zone 4 is comprised of 1-km^2 UTM cells that have an average of almost three slides per cell (5656 failures in 2002 UTM cells).

4.2.3 Biogeoclimatic zones

The classification and coding of UTM cells by their location in biogeoclimatic zones was based on the map "Biogeoclimatic Zones of the Queen Charlotte Islands", by Banner and Pojar (1982), which identifies four principal zones (Figure 26):

1. Coastal Western Hemlock Zone (CWHg), Western Hemlock-Sitka Spruce Subzone (or Queen Charlotte Subzone)
2. Coastal Cedar - Pine - Hemlock Zone (CCPH)[5]
3. Mountain Hemlock Zone (MH)
4. Alpine Tundra Zone (AT).

A summary of UTM cells and slope failures distribution by four biogeoclimatic zones is presented in Table 5.

The Queen Charlotte Subzone of the Coastal Western Hemlock Zone (Zone 1) occupies over 62% of the total land area, where some 40% of all failures occur (3345 failures in 1412 UTM cells). Average number of failures in this zone is 0.53 per square kilometer of the land area, and 2.37 failures per UTM cell. About 80% of UTM cells are in frequency class I (one to three slides per square kilometer).

About one-half of all slides occur in Zone 2 (Coastal Cedar-Pine-Hemlock), which occupies slightly over a quarter (26.4%) of the total land area. It has an average of 1.5 failure per square kilometer of the area, and 2.73 failures average per UTM cell.

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[5] The CCPH Zone has recently been assigned to the Coastal Western Hemlock Zone as a subzone (D. Meidinger, pers. comm., B.C. Min. For. Lands).

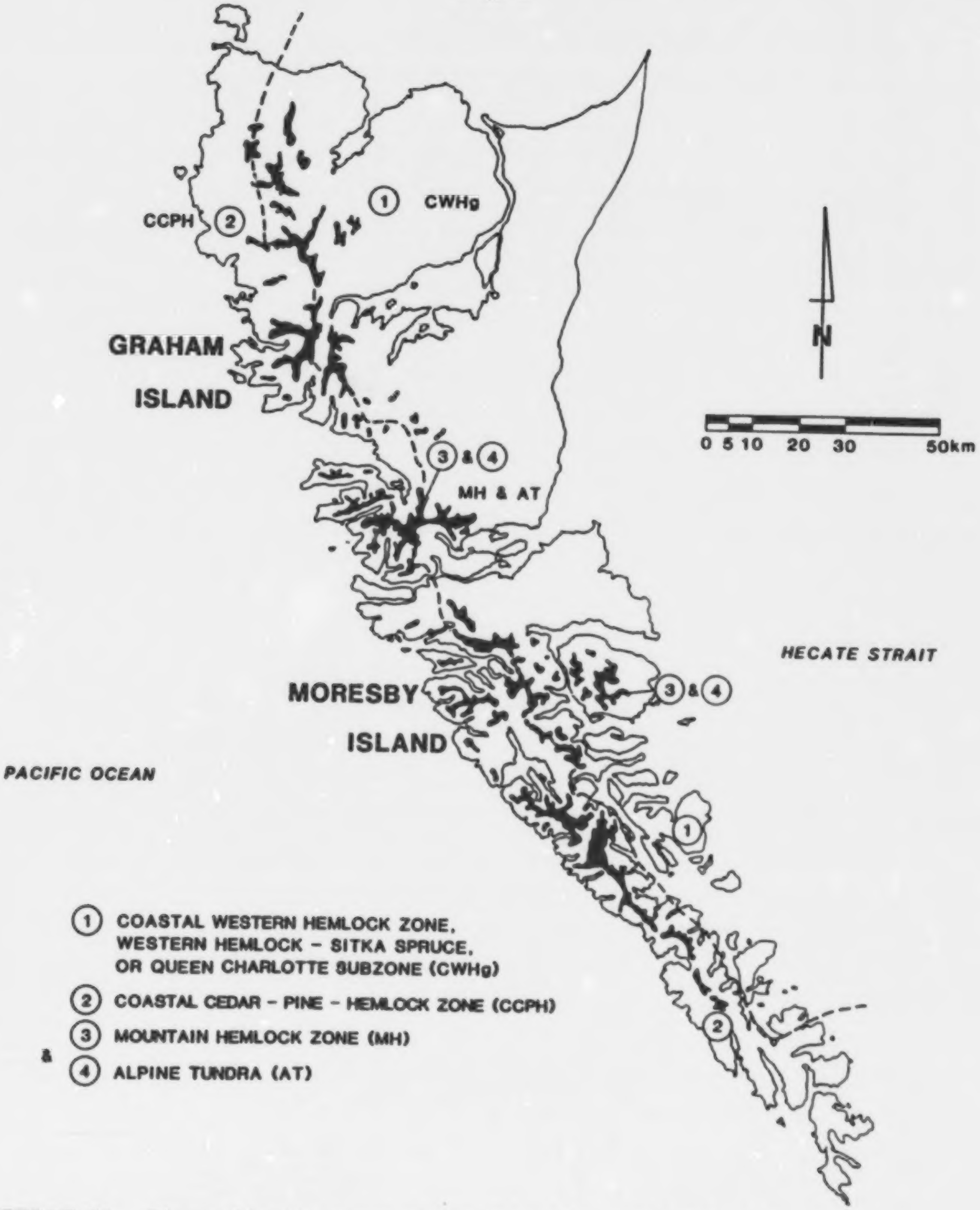
① CWHg
CCPH ②
GRAHAM ISLAND
N
0 5 10 20 30 50km
③ & ④
MH & AT
HECATE STRAIT
MORESBY ISLAND
③ & ④
PACIFIC OCEAN
①
②
① COASTAL WESTERN HEMLOCK ZONE, WESTERN HEMLOCK - SITKA SPRUCE, OR QUEEN CHARLOTTE SUBZONE (CWHg)
② COASTAL CEDAR - PINE - HEMLOCK ZONE (CCPH)
③ MOUNTAIN HEMLOCK ZONE (MH)
&
④ ALPINE TUNDRA (AT)

FIGURE 26. Biogeoclimatic zones of the Queen Charlotte Islands. (A. Banner and J. Pojar 1982)

TABLE 5. Slope failures by biogeoclimatic zone

BIOGEOCLIMATIC ZONE	Estimated Zone Area in km^2	% of total Q.C.I. land area	SLOPE FAILURES				AVE. NO. OF FAILURES/KM^2		FREQUENCY CLASSES					
									1-3 slides/km^2		4-7 slides/km^2		>8 slides/km^2	
			Number of Failures	%	Number of UTM cells	% All Cells / Zone Area	Total Land Area	UTM cell	Number of Failures	Number of UTM cells	Number of Failures	Number of UTM cells	Number of Failures	Number of UTM cells
1. CWHG (Coastal Western Hemlock Zone; Queen Charlotte Subzone)	6 254	62.9	3 345	40.2	1 412	44.8 / 22.6	0.53	2.37	1 950	1 142	1 194	248	201	22
2. CCPH (Coastal Cedar-Pine-Hemlock Zone)	2 622	26.4	3 923	47.1	1 434	45.5 / 54.7	1.50	2.73	1 803	1 038	1 773	359	347	37
3. MH (Mountain Hemlock Zone) 4. AT (Alpine Tundra Zone)	1 070	10.7	1 060	12.7	307	9.7 / 28.7	1.0	3.45	360	180	548	110	152	17
ALL ZONES	9 946	100.0	8 328	100.0	3 153	100.0 / 31.7	0.84	2.64	4 113	2 360	3 515	717	700	76

Almost three-quarters of UTM cells are in frequency class I, 25% of UTM cells are in the frequency class II, and the remaining cells are in class III.

Zones 3 and 4 (Mountain Hemlock Zone and Alpine Tundra Zone) were combined into a single unit, with an estimated area of 1070 km^2. Over 300 UTM cells -- about 29% of the area -- is subjected to intensive landslide activity, with an average of 3.45 failures per UTM cell.

4.2.4 Bedrock geology

Classification of bedrock geology in UTM cells containing slope failures was based on Sutherland Brown's geological maps of the Islands (1968). Each UTM cell listed on a compilation form was identified on the map and coded according to the geologic boundaries on the overlay as follows:

Code 1. Masset formation (TM)
Code 2. Skidegate formation (KS)
Code 3. Honna formation (KHO)
Code 4. Haida formation (KHA)
Code 5. Longarm formation (KL)
Code 6. Yakoun formation (JY)
Code 7. Maude formation (JM)
Code 8. Kunga formation (RKA)
Code 9. Karmutsen formation (RJKU, RKU, JKU, RKU$_2$ and RKU$_1$)
Code 10. Plutons - Post Tectonic (KTP)
Code 11. Plutons - Syntectonic (JS)
Code 12. Migmatite (JSM).

To correlate the intensity of landslide activity with different rock types, the area of each formation was compiled by individual NTS map sheets and used in the classification of UTM cells. The proportion of the area occupied by each rock formation was expressed as a percentage of the total land area of the Islands, as shown in Table 6.

In addition to 12 bedrock formations coded with numerals 1 to 12, there is an area of some 2658 km^2 (26.7% of the total area of the Islands) occupied by recent alluvium and glacial deposits, where no slope failures were observed.

Bedrock geology on the Queen Charlotte Islands consists mainly of three broad lithologic groups: volcanic, sedimentary, and metamorphic. As seen on Table 6, over 70% of all slope failures occur in areas dominated by volcanic rocks, which occupy more than half (53.7%) of the total land area, and almost three-quarters (73.3%) of the area underlain by all rock formations.

About three-quarters of volcanic rocks (75.7%) are "soft volcanics", made up of the Masset and Yakoun Formations. These rocks, generally highly fractured and strongly eroded by past glaciation, are termed soft volcanics because they continue to be easily weathered and eroded by present day processes (Lewis 1982). The Masset Formation consists of very thick accumulations of volcanic flows and pyroclastic rocks (alkali basalt and sodic rhyolite), while the Yakoun Formation is dominated by pyroclastic rocks characterized by porphyrite andesite agglomerate and tuffs. The remaining 24.3% are "hard" volcanics, mainly the massive basalt flows of the Karmutsen Formation, composed of basic lavas, related clastic rocks, and derived amphibolites and schists. There is a slightly higher proportion of "active" UTM cells on hard volcanic rocks (52% vs 38% on soft volcanics), and the average number of failures per square kilometer of land area is higher in hard volcanic rocks (1.38 vs 1.01 for soft volcanics).[6]

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[6] The values do not include the large bedrock slump-slides found to predominate in the Masset Formation, as discussed by Alley and Thomson (1978).

TABLE 6. Slope failures by broad bedrock formation groups (a) and by bedrock formation (b)

LITHOLOGY	Estimated Area in km^2	%	SLOPE FAILURES				AVE. NO. OF FAILURES/KM^2		FREQUENCY CLASSES					
									1-3 slides/km^2		4-7 slides/km^2		> 8 slides/km^2	
			Number of Failures	%	Number of UTM Cells	% All Cells Rock Unit	Bed-rock Area	UTM Cell	Number of Failures	Number of UTM Cells	Number of Failures	Number of UTM Cells	Number of Failures	Number of UTM Cells
Volcanic - soft (Masset, Yakoun)	4 044	55.5	4 081	49.0	1 551	49.2 38.3	1.01	2.63	1 986	1 159	1 717	351	378	41
Volcanic - hard (Karmutsen)	1 297	17.8	1 792	21.5	674	21.4 52.0	1.38	2.66	875	502	782	157	135	15
Sedimentary (Skidegate, Honna, Haida, Longarm, Maude & Kunga)	1 030	14.1	898	10.8	354	11.2 34.4	0.87	2.54	504	280	324	66	70	8
Intrusive and Metamorphic (Plutons and Migmatite)	917	12.6	1 557	18.7	574	18.2 62.6	1.70	2.71	748	419	692	143	117	12
ALL FORMATIONS	7 288	100.0	8 328	100.0	3 153	100.0 43.3	1.14	2.64	4 113	2 360	3 515	717	700	76

TABLE 6. (Continued)

BEDROCK FORMATION	ROCK GROUP	Est. Area in km^2	% of total Q.C.I.	SLOPE FAILURES				Ave. Number failures/km^2		FREQUENCY CLASSES					
										1-3 slides/km^2		4-7 slides/km^2		> 8 slides/km^2	
				No. of Failures	%	No. of UTM Cells	% all cells Form. Area	Total Formation Area	UTM Cell	No. of Failures	No. of UTM Cells	No. of Failures	No. of UTM Cells	No. of Failures	No. of UTM Cells
0. Quaternary & recent		2 658	26.8	-	-	-	-	-	-	-	-	-	-	-	-
1. Masset (TM)	volcanic (soft)	3 301	33.2	3 618	43.4	1 375	43.6 41.6	1.10	2.63	1 739	1 023	1 530	314	349	38
2. Skidegate (KS)	sedimentary	25	0.3	8	0.1	5	0.1 20.0	0.32	1.60	8	5	-	-	-	-
3. Honna (KHo)	sedimentary (clastic)	179	1.8	240	2.9	83	2.6 46.4	1.34	2.89	109	59	114	22	17	2
4. Haida (KHa)	sedimentary (clastic)	377	3.8	202	2.4	75	2.4 19.9	0.53	2.69	111	59	65	13	26	3
5. Longarm (KL)	sedimentary	85	0.8	69	0.8	32	1.0 37.6	0.81	2.16	44	27	25	5	-	-
6. Yakoun (JY)	volcanic (soft, calcareus)	743	7.5	463	5.6	176	5.6 23.7	0.62	2.63	247	136	187	37	29	3
7. Maude (JM)	sedimentary	4	-	-	-	-	-	-	-	-	-	-	-	-	-
8. Kunga (RJKU)	sedimentary (hardlimestone)	360	3.6	379	4.5	159	5.0 44.2	1.05	2.38	232	130	120	26	27	3
9. Karmutsen (RKA)	volcanic (hard)	1 297	13.0	1 792	21.6	674	21.4 52.0	1.38	2.66	875	502	782	157	135	15
10. Plutons-Post Tectonic (KTP)	intrusive	460	4.6	799	9.6	280	8.9 60.9	1.74	2.85	368	199	360	74	71	7
11. Plutons-Syn-tectonic (JS)	intrusive	436	4.4	742	8.9	288	9.2 66.0	1.70	2.58	371	215	325	68	46	5
12. Migmatite (JSM)	metamorphic	21	0.2	16	0.2	6	0.2 28.6	0.76	2.67	9	5	7	1	-	-
		9 946	100.0	8 328	100.0	3 153	100.0	1.14	2.64	4 113	2 360	3 515	717	700	76

Sedimentary rocks (Skidegate, Honna, Haida, Longarm, and Kunga formations) comprised about 14% of the land area, and account for almost 11% of all slides. Over one-half (57%) of these sedimentary rocks are "clastic", or particulate derived sandstones, siltstones, silty shales, and conglomerates (Skidegate, Honna, and Haida formations), and the remaining 43% are precipitated calcium carbonate rocks or limestone (Longarm, Kunga). Average number of failures per square kilometer of the estimated area was 0.87. Active UTM cells occupied about one-third (34.4%) of the total area of this group, with an average of 2.54 failures per 1-km^2 cell.

Intrusive igneous rocks and Migmatite occupied some 12% of the area of all formations and accounted for 18.7% of all slides. This group has the highest average number of failures: 1.70 per square kilometer for the land area of this group, and 2.71 failures per UTM cell.

A numerical analysis of each of the 12 bedrock formations is presented in Table 6. According to this data, the most active processes of slope erosion by soil mass movement occur on the areas underlain by igneous rocks -- Post Tectonic and Syntectonic Plutons. There are 742 slope failures (8.9% of all failures) in 288 one-km^2 UTM cells recorded in Formation 11, (Syntectonic Plutons) which has an estimated area of 436 km^2 (4.4% of the total Islands land area). The active area (288 UTM cells with landslide initiation points) was fairly high: it occupied 66% of the formation area and had 2.58 failures per square kilometer, while average number of failures for the entire 436 km^2 area was 1.7 per 1 km^2. About three-quarters of active UTM cells (74.6%) had one to three failures per 1 km^2 (frequency class I), 23.6% of UTM cells are in frequency class II (four to seven failures per square kilometer), and the remaining 1.8% cells in frequency class III (more than eight failures per 1 km^2).

Similar conditions were noted in bedrock formation 10 (Post Tectonic Plutons), which showed the highest average number of failures per 1 km^2 of the formation area (1.74 failures per square kilometer), and per UTM cell (2.85 failures per 1-km^2 cell).

The most widely occurring volcanic rocks were subaerial basalt flows of the Masset Formation, which accounted for one-third (33.2%) of the Islands land area, and nearly one-half (43.4%) of all slides. Average frequency in this formation was 1.10 slides per square kilometer of total area, and 2.63 slides per 1-km^2 UTM cell. Distribution of three frequency classes in the Masset Formation was comparable to two other volcanic rock formations -- Karmutsen and Yakoun.

Among sedimentary rocks, two formations -- the Honna and Kunga -- have the highest average number of failures per square kilometer of the formation area and per UTM cells, and a relatively high proportion of active UTM cells within the total Formation area.

No slope failures were observed in the 4-km^2 area of the Maude Formation.

4.2.5 Land use

Four broad classes of present land use were determined from stereoscopic examination of the working set of aerial photographs used to identify landslides. As most of the survey area is forested (Land use class 1), the air photo analysis was concentrated mainly on UTM cells showing any degree of disturbance. The land use classes were coded as follows:

Code 1. Forested (vegetated or undisturbed areas)
Code 2. Logging activity
Code 3. Road construction
Code 4. Mining.

A summary of slope failures by four land use classes presented in Table 7 indicates that over 90% of slope failures were recorded in forested or undisturbed areas (land use class 1). Average number of slides per 1-km^2 UTM cell for this class is 2.63, which is slightly lower than the average for the areas disturbed by logging (2.74 slides per UTM cell).

Class 2 (areas with recent logging activities) account for 764 slope failures recorded in 279 one-km^2 UTM cells. The average number of slides per 1 km^2 is 2.74. About one-half of slope failures occur in frequency class I (one to three failures per square kilometer), 42% in frequency class II (four to seven failures per square kilometer), and the remaining 7% in class III (eight or more failures per square kilometers).

4.2.6 Elevation above sea level

Elevation classes of UTM cells were determined directly from 1:50 000 scale topographic maps. Based on 500-ft (152 m) intervals, the seven elevation classes were coded numerically from 1 (sea level to 150 m) to 7 (elevation more than 900 m ASL):

Code 1. El.ASL from 0 to 150 m (sea level to 500 ft)
Code 2. El.ASL from 151 to 300 m (500 ft to 1000 ft)
Code 3. El.ASL from 301 to 450 m (1001 ft to 1500 ft)
Code 4. El.ASL from 451 to 600 m (1501 ft to 2000 ft)
Code 5. El.ASL from 601 to 750 m (2001 ft to 2500 ft)
Code 6. El.ASL from 751 to 900 m (2501 ft to 3000 ft)
Code 7. El.ASL from 900m$^+$ (3001 ft +)

Table 8 shows the number of failures and 1-km^2 UTM grid cells summarized by seven elevation classes.

More than one-third (34.8%) of all slope failures were recorded in elevation class 3, about 30% in elevation class 2, and 16.3% in elevation class 4. The number of failures in the remaining elevation

TABLE 7. Slope failures by land use class

LAND USE CLASS	SLOPE FAILURES IN UTM CELLS					FREQUENCY CLASSES					
						1-3 slides/km^2		4-7 slides/km^2		> 8 slides/km^2	
	No. of Failures	% of Total	No. of UTM Cells	% of Total	Ave. No. of slides per UTM	No. of Failures	No. of UTM cells	No. of Failures	No. of UTM cells	No. of Failures	No. of UTM cells
1. Forested	7 522	90.3	2 854	90.5	2.63	3 694	2 135	3 181	649	647	70
2. Disturbed by logging	764	9.2	279	8.9	2.74	391	208	320	65	53	6
3. Road construction	41	0.5	19	0.6	2.16	27	16	14	3	-	-
4. Mining	1	-	1	-	-	1	1	-	-	-	-
TOTAL	8 328	100.0	3 153	100.0	2.64	4 113	2 360	3 515	717	700	76

TABLE 8. Slope failures by elevation ASL class

ELEVATION CLASS	SLOPE FAILURES IN UTM CELLS					FREQUENCY CLASSES					
						1-3 slides/km^2		4-7 slides/km^2		>8 slides/km^2	
	No. of Failures	%	No. of UTM Cells	%	Ave. No. Failures per UTM	No. of Failures	No. of UTM cells	No. of Failures	No. of UTM cells	No. of Failures	No. of UTM cells
1. 0-150m (0 - 500' ASL)	634	7.6	335	10.6	1.89	467	300	159	34	8	1
2. 151-300m (501-1000' ASL)	2 468	29.6	1 029	32.6	2.40	1 408	827	909	186	151	16
3. 301-450m (1001-1500'ASL)	2 895	34.8	1 043	33.1	2.77	1 348	754	1 290	261	257	28
4. 451-600m (1501-2000'ASL)	1 355	16.3	457	14.5	2.96	554	310	627	128	174	19
5. 601-750m (2001-2500'ASL)	679	8.2	207	6.6	3.28	241	123	376	77	62	7
6. 751-900m (2501-3000'ASL)	269	3.2	71	2.3	3.79	78	37	143	29	48	5
7. 901m (3001' ASL)	28	0.3	11	0.3	2.54	17	9	11	2	-	-
TOTAL	8 328	100.0	3 153		2.64	4 113	2 360	3 515	717	700	76

classes is considerably lower: about 8% in elevation classes 1 and 5, 3.2% in class 6, and only 0.3% (28 failures) in elevation class 7.

The average number of active 1-km^2 UTM cells follows a similar pattern: there are 1043 UTM cells (33.1% of all cells) in elevation class 3, 1029 cells (32.6%) in class 2, 457 cells (14.5%) in class 4, 335 cells (10.6%) in class 1, 71 cells (2.3%) in class 6, and 11 UTM cells (0.3%) in elevation class 7.

The average number of failures recorded in 1-km^2 UTM cells increases upward from elevation class 1 to elevation class 6, dropping to an average of 2.5 failures per square kilometer in elevation class 7:

Elevation Class	Avg. failures/km^2
1	1.89
2	2.40
3	2.77
4	2.96
5	3.28
6	3.79
7	2.54

Almost two-thirds of all slides and active UTM cells (64.4%) of all slope failures, and 65.7% of UTM cells occur in elevation classes 2 and 3.

4.2.7 Slope steepness

The average degree of steepness of UTM cells with slope failure initiation points was estimated directly from the working set of 1:50 000 topographic maps. Five slope steepness classes expressed as 30% intervals were calculated from the measurements of 100-ft contours within 1-km^2 cells:

Code 1. 0-30%
Code 2. 31-60%
Code 3. 61-90%
Code 4. 91-120%
Code 5. 121 and up.

Table 9 is a summary of slope failures and UTM cells classified by five slope steepness classes.

Almost two-thirds of all slides were recorded within the 1-km^2 UTM cells located on slopes having an average incline of 60-90% (slope steepness class 3). Actual location for most of these failures is 65-75% steepness range.

In class 2 steepness there are about 33.9% of UTM cells with 26.2% of slope failures. On very steep slopes of steepness class 4 and 5, as well as on slopes of class 1, there is a considerable reduction in the number of active UTM cells and slides: 7.5% of failures were recorded in steepness class 4, 2.0% in class 1, and only 0.2% (16 slides) in class 5.

The average number of failures per 1-km^2 cell increased with the steepness classes:

Steepness class	Avg. failures/km^2
1	1.58
2	2.04
3	2.98
4	3.43
5	4.00

4.2.8 Slope aspect

The general direction of UTM cells within the watershed was expressed as eight slope aspect classes, based on the diagram shown in Figure 27. Each 1-km^2 UTM cell was classified directly on

TABLE 9. Slope failures by steepness class

SLOPE STEEPNESS CLASS	SLOPE FAILURES IN UTM CELLS					FREQUENCY CLASSES					
						1-3 slides/km^2		4-7 slides/km^2		> 8 slides/km^2	
	No. of Failures	%	No. of UTM Cells	%	Ave. per UTM Cell	No. of Failures	No. of UTM cells	No. of Failures	No. of UTM cells	No. of Failures	No. of UTM Cells
1. 30% (17°)	169	2.0	107	3.4	1.58	147	102	22	5	-	-
2. 31 - 60% (17° - 31°)	2 178	26.2	1 069	33.9	2.04	1 541	943	553	116	84	10
3. 61 - 90% (32 - 42°)	5 341	64.1	1 791	56.8	2.98	2 210	1 205	2 586	528	545	58
4. 91 - 120% (43° - 50°)	624	7.5	182	5.8	3.43	209	108	344	66	71	8
5. 120% (51°)	16	0.2	4	0.1	4.0	6	2	10	2	-	-
TOTAL	8 328	100.0	3 153	100.0	2.64	4 113	2 360	3 515	717	700	76

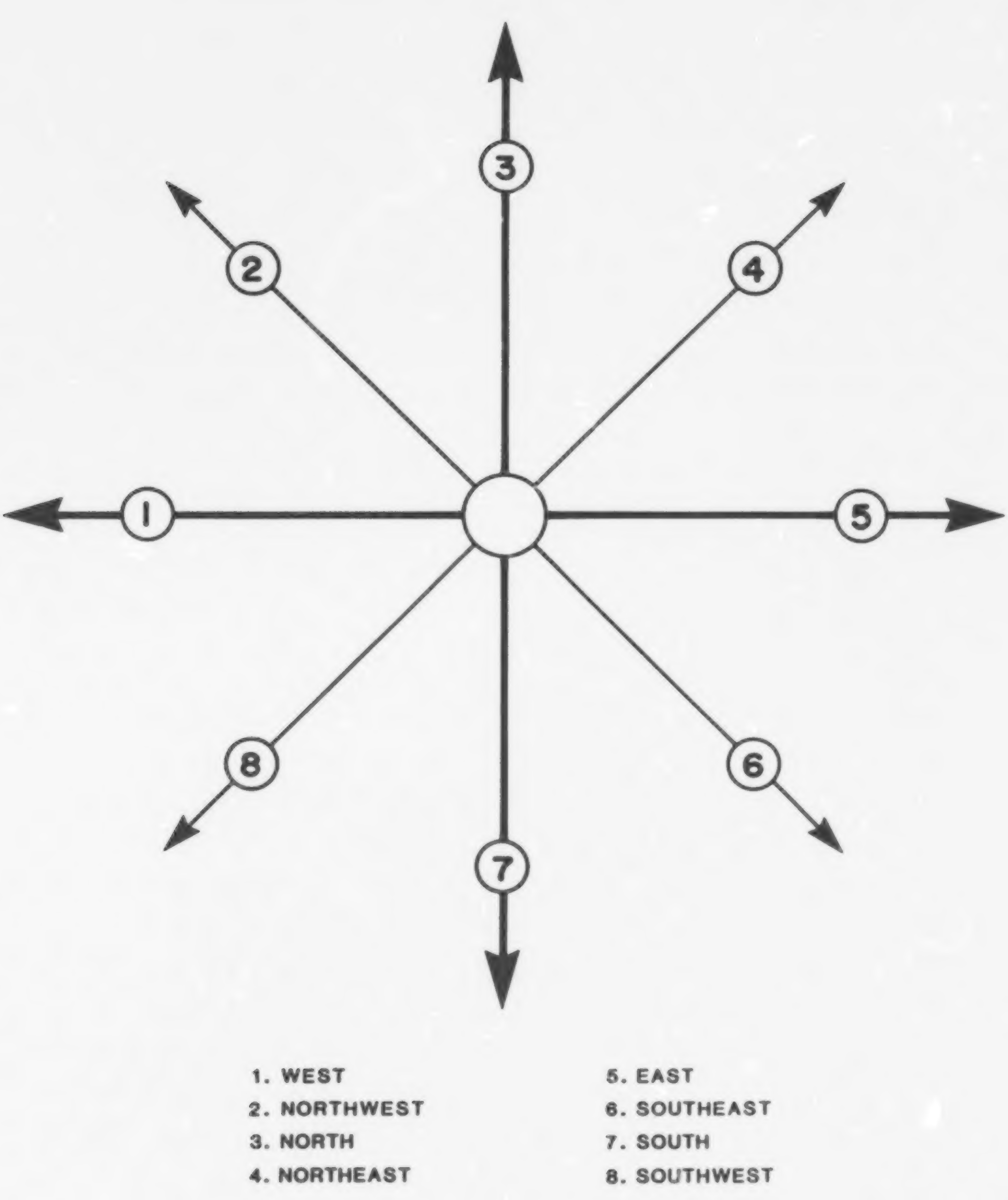
3
2
4
1
5
8
6
7
1. WEST
2. NORTHWEST
3. NORTH
4. NORTHEAST
5. EAST
6. SOUTHEAST
7. SOUTH
8. SOUTHWEST

FIGURE 27. Slope aspect classes.

topographic map. In cases where the UTM cell includes more than one direction (e.g., along a boundary of two drainage basins), the cell was classified according to a dominant aspect of the cell where a majority of slide initiation points are located. When, for example, out of a total of five slides in a single UTM cell, two were on a south-facing slope, and three occupied a north-eastern slope, the cell was classified as slope aspect class 4 (Northeast).

The following coding system has been used to indicate slope aspect classes of UTM grid cells:

Aspect class	General direction
1	West
2	Northwest
3	North
4	Northeast
5	East
6	Southeast
7	South
8	Southwest

A condensed summary of UTM cells and slope failures grouped by eight slope aspect classes is presented in Table 10.

The most active slopes, with the highest number of slope failures and UTM cells, were recorded on aspect classes 6 (Southeast), 8 (Southwest), and 4 (Northeast). There are 2398 slope failures, or 28.8% of all slides, recorded in 843 one-km^2 UTM cells (26.7% of all UTM cells) within slope aspect class 6. This aspect class also had the highest average number of failures per square kilometer: 2.84. The number of failures in aspect classes 8 and 4 was about 10 % lower: 1457 slides in class 8, and 1418 in class 4.

TABLE 10. Slope failures by aspect class

SLOPE ASPECT CLASS	SLOPE FAILURES IN UTM CELLS					FREQUENCY CLASSES					
						1-3 slides/km^2		4-7 slides/km^2		>8 slides/km^2	
	No. of Failures	%	No. of UTM Cells	%	Ave. per UTM cell	No. of Failures	No. of UTM cells	No. of Failures	No. of UTM cells	No. of Failures	No. of Cells
1. W (West)	325	3.9	165	5.2	1.97	231	146	75	17	19	2
2. NW (Northwest)	692	8.3	310	9.8	2.23	422	253	254	55	16	2
3. N (North)	359	4.3	142	4.5	2.53	199	109	152	32	8	1
4. NE (Northeast)	1 418	17.1	533	16.9	2.66	697	396	587	122	134	15
5. E (East)	827	9.9	293	9.3	2.82	360	206	375	77	92	10
6. SE (Southeast)	2 398	28.8	843	26.7	2.84	1 041	596	1 141	225	216	22
7. S (Scuth)	852	10.2	308	9.8	2.77	404	227	337	69	111	12
8. SW (Southwest)	1 457	17.5	559	17.8	2.61	759	427	594	120	104	12
TOTAL	8 328	100.0	3 153	100.0	2.64	4 113	2 360	3 515	717	700	76

The West (class 1) and the North (class 3) aspects had the lowest number of slope failures: 325 slides (3.9%) occur in 165 UTM cells (5.2% of all cells) in aspect class 1; and 359 (4.3%) slides occur in 142 UTM cells (4.5% of all cells), in aspect class 3.

Average number of slides per 1-km^2 of all UTM cells ranged from a low 1.97 in slope aspect class 1 (West), to a high of 2.84 in aspect class 6. In the remaining aspect classes, the averge number of slides per square kilometer was as follows:

2.23 in class 2 (Northwest)
2.53 in class 3 (North)
2.61 in class 8 (Southwest)
2.71 in class 4 (Northeast)
2.77 in class 7 (South)
2.82 in class 5 (East)

4.2.9 Position on slope

To determine the particular position on the slope occupied by 1-km^2 UTM grid cells, a slope was divided into three imaginary segments -- lower, middle and upper -- each approximately one-third of the slope. The UTM cells were classified according to their topographic positions and placed into one of the following three classes:

Class 1. Lower slope;
Clase 2. Middle slope;
Class 3. Upper slope.

A summary of slope failures by general position classes is presented in Table 11. More than one-half of slope failures occur in class 3 (about 54.3% of all slides and 51.1% of UTM cells), which also had the highest average number of failures per UTM cells.

TABLE 11. Slope failures by general position class

SLOPE POSITION	SLOPE FAILURES IN UTM CELLS					FREQUENCY CLASSES					
						1-3 slides/km^2		4-7 slides/km^2		> 8 slides/km^2	
	No. of Failures	%	No. of UTM Cells	%	Ave. No. Failures per UTM	No. of Failures	No. of UTM cells	No. of Failures	No. of UTM cells	No. of Failures	No. of UTM cells
1. Lower slope position	860	10.3	422	13.4	2.04	561	362	261	56	38	4
2. Middle slope position	2 947	35.4	1 120	35.5	2.63	1 477	845	1 221	249	249	26
3. Upper slope position	4 521	54.3	1 611	51.1	2.81	2 075	1 153	2 033	412	413	46
TOTAL	8 328	100.0	3 153	100.0	2.64	4 113	2 360	3 515	717	700	76

The middle and lower slope positions showed a considerable decrease in the number on slides and UTM cells: about 35.4% of slope failures were recorded in class 2, and 10.3% in class 1.

Average number of slides per 1-km^2 UTM cells is 2.04 in class 1, 2.63 in class 2, and 2.81 in class 3.

4.3 Discussion

General

From a stereoscopic airphoto analysis of the entire area of the Islands (about 10 000 km^2), a total of 8328 slope failures were identified. Initially, the slope failures were mapped within some 560 "active" segments of drainage basins, having an estimated cumulative area of 2553 km^2, which indicates that over one-quarter (26%) of the entire land area of the Islands is subjected to mass movement processes.

Because the boundaries of these "active" drainage units were often arbitrary, the initiation points of 8328 identified slope failures were recorded in 3153 one-kilometer square UTM grid cells by superimposing the UTM grid over the 1:50 000 scale working maps. If each UTM cell is assumed to represent 1-km^2, which contains at least one slope failure initiation point, then the "active" area of affected UTM cells occupies almost one-third of the total land base.

Slope failure frequency

The intensity of landslide activity was expressed as a number of failures occurring in 1-km^2 of the gross land area of the Islands (9946 km^2), or in active drainage units (2553 km^2), and as a number of slope failure initiation points recorded in each of the 3153 UTM grid cells. Depending which land base is used in the analysis (gross area, area of 560 active drainage units, or UTM grid cells), the distribution of the 8328 slope failures compiled in this inventory, and the average intensity levels or frequency, may be presented as:

- an average number of failures per 1 km^2 of the total land area (9946 km^2) of the Queen Charlotte Islands, or 8328:9946 = 0.84 failures per square kilometer;
- an average number of failures mapped in some 2553 km^2 active drainage units, or 8328:2553 = 3.26 failures per square kilometer; and
- an average number of slope failure initiation points in 3153 1-km^2 UTM grid cells, or 8328:3153 = 2.64 per square kilometer.

Comparison to other studies

The above frequency figures (0.84, 3.26, and 2.64 events per square kilometer and per one UTM cell), suggest that the landslide activity on the Queen Charlotte Islands is generally high. The attempt to find similar studies in the Pacific Northwest and British Columbia for a comparison - was only partly successful (i) because the Queen Charlotte Islands are unique in many respects, and (ii) because their susceptibility to mass wasting processes is probably among the highest on the continent. Five studies (two in British Columbia, two in Oregon, and one in Washington) were selected for a comparison of average slope failure frequencies (Table 12).

Cumulative area of these five studies is 732.7 km^2, with a total of 1588 failures (821 failures or 51.7% recorded in forested, and 767 or 48.3% in clearcut and road construction areas). Because of a high proportion of clearcut and road construction areas involved, the Cascade Mountains study and the Olympic Peninsula study showed average frequencies of 5.74 and 4.43 failures per square kilometer. However, the average frequency for all five studies was 2.17 failures per 1 km^2 (1588 failures; 732.7 per square kilometer), which is slightly lower than the average number of initiation points in UTM cells (2.64 per cell), and considerably lower than the average frequency calculated on the basis of active drainage units in this study (3.26 per square kilometer). Also, over 90% of all failures compiled for the Queen Charlotte Islands study were recorded in forested areas, while almost one-half (48.3%) of failures in other study areas were related to clearcut and road construction.

TABLE 12. Comparison of slope failure frequency data from various studies

TABLE 12 Comparison of slope failure frequency data from various studies

Studies	Study area (km^2)	Total no. slope failures recorded	Avg. no. failures/km^2	No. and % failures recorded in Forested areas	Clearcut and road construction areas
Coast Mounts B.C. (O'Loughlin 1972)	276.7	58	0.21	29 (50%)	29 (50%)
Logging watershed on Queen Charlotte Islands, B.C. (Rood 1984)	350	1192	3.4	729 (61.2%)	463 (38.8%)
Cascade Mountains, Oregon (Swanson and Dyrness 1975)	64.2	130	2.02	31 (23.8%)	99 (76.2%)
Cascade Mountains, Oregon (Morrison 1975)	17.4	100	5.74	7 (7%)	93 (93%)
Olympic Peninsula, Wash. (Fiksdahl 1974)	24.4	108	4.43	25 (23.2%)	83 (76.8%)
Queen Charlotte Island, B.C. (This study)	9946	8328	0.84	7522 (90.3%)	806 (9.7%)

- "active" draingage units: 253
- avg. no. failures/1-km^2 of active drainage units: 3.26
- "active" UTM grid cells: 3153
- avg. no. failures/1-km^2 UTM cell: 2.64

Slope failure frequency classes by landscape characteristics

To correlate the occurrence and intensity of slope failures with significant landscape factors, each of the 3153 one-km^2 UTM cells was classified by nine dominant landscape characteristics, analyzed, and then grouped into 11 actual frequency classes (from 1 to more than 11 failures per UTM cell). Series of statistical tables compiled for this report present interesting data on slope failure intensities occurring in UTM cells with different topographic or climatic characteristics. This analysis provided useful information on the general frequency patterns in UTM cells grouped into nine classes of landscape attributes and may be used as a guide in the development of landslide susceptibility indicators.

Digital data on the classification of 3153 UTM one-km^2 cells classified by nine landscape attributes were analyzed independently by Dr. Mark Sondheim, B.C. Ministry of Environment. (His findings are included in this report as Appendix 3, "A critique of the methodology used by Philip Gimbarzevsky in Regional overview of mass wasting on the Queen Charlotte Islands'.")

The frequency distribution of slope failure events in 3153 UTM cells suggests there is a definite correlation of landslide intensity with landscape attributes, which influences the intensity levels of mass wasting processes. The relative significance of the individual attributes can only be speculated. In some cases a single factor, such as type of the underlying bedrock, slope steepness, or aspect, may be a main cause of landslide activity. However, the inventory data presented in this report indicate that in many cases, the most significant factor that exerts a strong influence over the intensity level of mass wasting is usually a combination of two or more landscape attributes, for example, a combined effect of topography, climatic conditions, and physical land characteristics.

5 SUMMARY

1. A total of 8328 slope failures identified on aerial photographs within active drainage units were presented on 1:50 000 scale topographic maps. The initiation points of these slides, occurring in 3153 one-km^2 UTM grid cells, were displayed graphically as slope failure frequencies, ranging from a single failure per UTM cell to more than 11 per cell.

2. The average number of failures for all 3153 active UTM cells is 2.64 failures per 1-km^2 cell. The average frequency for the entire land area of the Queen Charlotte Islands (9946 km^2) is 0.84 failures per square kilometer, including the Queen Charlotte Lowlands.

3. Based on an estimated average failure size of 1.5 ha, the estimated total area denuded by 8328 slides was 12 492 ha, or about 125 km^2, which represents 1.25% of the entire Queen Charlotte Islands land area.

4. The concentration levels of landslides were expressed as three intensity classes:

   Class I (one to three slides per square kilometer) - occurs in 74.9% of UTM cells and includes almost one-half (49.4%) of all slope failures.

   Class II (four to seven slides per square kilometer) - occurs in 22.7% of UTM cells and includes 42.2% of all slope failures.

   Class III (eight or more slides per square kilometer) - occurs only in 2.4% of UTM cells and includes 8.4% of all slope failures.

5. Tabular summaries derived from the analysis of 3153 active UTM cells were, classified by nine dominant landscape characteristics and actual frequency classes (from 1 to 11^+ failures per square kilometer). These provided useful indicators for correlating of the occurrence of landslides and their intensity, with the following attributes:

   Physiography
   Precipitation
   Biogeoclimatic zone
   Bedrock geology
   Land use
   Elevation ASL
   Slope steepness
   Aspect
   Position on slope

6. Physiography

The most active was the major physiographic subdivision "A" -- the Queen Charlotte Ranges, where 58% of all slope failures occurred in an area of 2744 km^2, which represented about 27.6% of the total land area of the Islands. There were 1776 active UTM cells, comprising almost two-thirds (64.7%) of the subdivision land area. Average number of failures per square kilometer of the subdivision's land area was 1.76, or about 100% higher than the average (0.84 failures per square kilometer) for the total land area of the Islands. The average frequency of 2.72 failures per UTM cell was also higher than the average (2.64 failures per cell) for all UTM cells. The intensity of slope failure was mostly distributed among the regional areas of the Queen Charlotte Ranges (major physiographic subdivision "A"), as indicated by the average number of slides per UTM cell:

Moresby Ranges (No. 5)	2.75 failures/UTM cell
Kermode Mountains (No. 4)	2.74 failures/UTM cell
San Christoval Mntns. (No. 3)	2.74 failures/UTM cell
East Coast Mountains (No. 8)	2.73 failures/UTM cell
Graham Ranges (No. 2)	2.73 failures/UTM cell

7. Precipitation zones

About 68% of slope failures occurred in the precipitation zone 4 (which has more than 3665 mm of mean annual total precipitation); the average number of slope failures in 2002 active UTM cells in this zone was 2.82 failures per cell. The average frequency in the precipitation zone 3 (2035-2225 mm/yr) was 2.33 failures per square kilometer.

8. Biogeoclimatic zones

Almost one-half of all slides (47.1%, or 3923 slides) occurred in zone 2 (Coastal Cedar-Pine-Hemlock Biogeoclimatic Zone), which occupies 26.4% of total land area of Queen Charlotte Islands. The average frequency for a total of 1434 active UTM cells in this zone was 2.73 failures per UTM cell.

9. Bedrock geology

Over 70% of slope failures occurred in areas underlain by volcanic rocks of the Masset, Yakoun, and Karmutsen formations, which occupy about 53% of the total land area. Almost-one half (49%) of all failures have occurred in about 40% of areas underlain by soft volcanics (Masset and Yakoun), while an estimated 13% of the total area underlain by hard volcanics accounts for over 21% of all slides. The active UTM cells extend over 42% of the volcanic rock area, and had an average of 1.1 failures per square kilometer of the land area, or 2.64 failures per UTM cell.

The Post Tectonic Plutons had the highest frequency of slope failures: 2.85 failures per UTM cell and 1.74 failures per square kilometer of the formation area.

Much lower frequencies (2.38 and 2.16 failures per UTM cell) were recorded in active UTM cells underlain by sedimentary rocks of Kunga and Longarm formations.

10. Land use

Disturbances by logging and road construction activity were recorded in 298 UTM cells containing some 805 slope failures identifiable on the 1:50,000 scale aerial photography. Each of these UTM cells contained areas of both logged and forested land -- in some cases only small areas of logged terrain were present within the cell. Consequently, the average number of failures per UTM cell (2.70 failures per square kilometer) was only marginally higher than the average frequency for forested terrain (2.63 fiaulres per square kilometer).

Much higher levels of landslide activity on logged areas of the Queen Charlotte Ranges have been measured by Rood (1984), who reported landslide frequencies up to 29.7 failures/per square kilometer. Rood's study demonstrated the advantages of using recent (1982), large scale (1:10,000) colour aerial photography under high stereoscopic magnification for mapping small landslides in logged areas. He also completely separated logged and forested terrain in his inventory, providing a more accurate account of the effect of logging and road building on slope stability.

11. Elevation ASL

Almost two-thirds of the total number of slope failures in active UTM cells (64.4% and 65.7%, respectively) occurred in the elevation classes 2 and 3 (El.ASL, 151-450 m), with an average of 2.40 failures per UTM cell in elevation class 2 (151-300 m), and 2.77 failures per UTM cell in class 3 (Elev. ASL, 301-450 m).

12. Slope steepness classes

More than one-half (56.8%) of UTM cells with over 64% of all slides occurred on class 3 slopes (61-90%), with an average of 2.98 failures per UTM cell. About two-thirds of UTM cells of this steepness class (67.3%) had one to three failures per square kilometer, 29.5% (528 cells) were in the four to seven failures per square kilometer frequency class, and the remaining 58 UTM cells (3.2%) had more than eight failures per UTM cell. Average number of failures per 1-km^2 UTM cell was a low of 1.58 failures per square kilometer in class 1 (slopes less than 30%), and 4.0 per square kilometer in steepness class 5 (120$^+$%).

13. Slope aspect

More than one-quarter (26.7%) of UTM cells and 28.8% of all slides, with an average of 2.84 failures per square kilometer, were located in aspect class 6 (Southeast). This aspect class had the highest average number of slope failures per UTM cell (2.84), followed (in a decreasing order) by aspect classes 5 (E), 7 (S), and 4 (NE), with average frequencies of 2.82, 2.77, and 2.66 failures per UTM cell.

About two-thirds (65.9%) of all slides, and 63% of active UTM cells were located in the above aspect classes.

14. Slope position

More than one-half (54.3%) of slope failures and 51.1% of active UTM cells were recorded on upper slope positions (slope position class 3), with an average of 2.81 failures per square kilometer. About 35.5% of slope failures and UTM cells were in class 2 (Middle slope positions), and slightly more than 10% of UTM cells with an average of 2.04 failures per square kilometer, occurred on lower slopes (slope position class 1).

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APPENDIX 1. A critique of the methodology used by Philip Gimbarzevsky in "Mass Wasting on the Queen Charlotte Islands: a Regional Inventory", Mark Sondheim, Ph.D., Surveys and Resource Mapping Branch, B.C. Ministry of Environment and Parks

Purpose and Methodology of the Study

This study was aimed at providing an inventory of the landslides in the Queen Charlotte Islands and at describing the type of land subjected to slide activity. Nine landscape classifications, subdivided into categories and quantified in terms of magnitude, were examined. These included (with the number of categories in parenthesis): physiography (10), precipitation (4), biogeoclimatic zone (4), bedrock geology (12), land use (4), elevation (7), slope steepness (5), aspect (8), and slope position (3).

All landslides identified on 1:50 000 aerial photographs were allocated to 1-km^2 UTM cells, the basic mapping units of the study. In total, 8328 slides were found in 3153 cells of the 9946 cells covering the Islands. For those 3153 active cells, the categories for each of the nine classifications were recorded and entered into a computer. No data were collected for the 6793 cells without visible slide activity. However, for each category of the first four classifications (physiography, precipitation, biogeoclimatic zone, and bedrock geology) the total area within the Charlottes was determined.

A cell was considered to belong to a given category if that category was dominant in the cell or if it was simply present in the cell, depending upon the classification. For example, consider a hypothetical cell in which one slide is present. The cell is occupied by 60% forest, 10% clearcut, and 30% water. Assume that the slope ranges from 0 to 40° with an average of approximately 25° for the non-water area. The database record for the cell would list the slope steepness as class 2 (17-31°), the land use as class 2 (presence of logging activity), and the number of slides as 1. (The category codes for the other seven classifications would also be provided.) The cell would also be included in the cell counts for slope steepness class 2 and land use class 2. For another cell with identical characteristics but no slides, there would be no specific database record for the cell, but it would be counted indirectly in the area assessments for the categories of the first four classifications.

The cell records and the data for the categories of all nine classifications allowed six variables to be determined:

1. the percent of the study area's 8328 slides found in the category;
2. the percent of the study area's 3153 active cells found in the category;
3. the ratio of the number of slides in the category to the number of active cells (slides per square kilometer);
4. the number of slides and cells in frequency class I (one to three slides per cell) for each category;
5. the number of slides and cells in frequency class II (four to seven slides per cell) for each category;
6. the number of slides and cells in frequency class III (eight or more slides per cell) for each category.

For the first four classifications, where area measurements for all of the Charlottes were collected, it was possible to calculate the following three variables as well:

7. the percent area of the Queen Charlotte Islands occupied by the given category;
8. the percent of the total area within the category which was found within cells with landslide activity;
9. the ratio of the number of slides in the category to the total area occupied by the category (slides per square kilometer).

Given the inventory rationale for the study, the methodology as described was appropriate. For example, for the summary statistics generated, it is clear that although the Moresby Ranges occupy only 9.7% of the area of the Charlottes, 22.4% of the total number of slides in the Charlottes are found there. Cells with average slopes ranging from 32 to 42° (slope steepness class 3) contain 64.1% of the total number of slides, whereas only 7.7% of the slides are found in cells with slopes averaging ⩾43° (slope steepness classes 4 and 5). Of the 5341 slides (in 1791 cells) in slope class 3, 2210 (in 1205 cells) fall into slide frequency class I, 2586 (in 528 cells) lie in frequency class II, and 545 (in 58 cells) are in frequency class III. These statistics and many others clearly indicate (1) the general landscape and characteristics associated with landslide occurrence on the Queen Charlotte Islands, and (2) the magnitude of the landslide phenomenon.

Extension of the Analysis

An example of the kind of analysis that can be easily performed on the active cell database involves an examination of the rate of slides per hectare as a function of physiographic region and slope steepness class. The original 10 physiographic regions have been reduced to 6 by amalgamation: (1) Masset and Langara Plains; (2) Kumshewa Uplands; (3) Skidegate Plain; (4) Graham Ranges; (5) San Christoval, Kermode, and East Coast Mountains and Kunghit Plain; (6) Moresby Ranges. Similarly, the five slope steepness classes have been reduced to four: (1) <17°; (2) 17-31°; (3) 32-42°; (4) >42°. Table A1 is a contingency (or cross-tabulation) table showing the number of recorded slides for each of the 24 combinations of region and slope classes. The number of active cells for each combination are provided on Table A2. Also included on both tables are the marginals, i.e., the sums for each row and column giving the total number of cells in each region and slope steepness class, respectively. The grand total for each table is provided in the lower right, 8328 slides for Table A1 and 3153 cells for Table A2. The ratio of each value in Table A1 to its corresponding value in Table A2 is given in Table A3.

From Table A3 several observations may be made. Looking first at the marginals, regions 1 and 2 appear to have much lower slides per active cell ratios compared to the other four regions. However, the ratio varies more as a function of slope (1.58 for class 1 to 3.44 for class 4) than it does as a function of region (2.00 for region 1 to 2.75 for region 6). The body of the table shows that the variation appears to be controlled mainly by the column (i.e., the slope steepness class) in which any given value falls. It is not clear whether the changes in the ratio for the regions are strictly the result of the regions being dominated by different slope classes.

The analysis of the active cell data may be carried further with the use of statistical techniques. Because the entire area of the Charlotte was studied (i.e., the sample includes the entire population), it might be argued that statistical theory does not apply. Nevertheless, one can apply statistical methods to provide indications of relationships, comparing the observed values with those that might be expected if random chance were the dominant influence.

The ratios in Table A3 cannot be directly studied statistically, but the number of slides (Table A1) can. The question becomes one of defining what the expected number of slides would be if the results were random. The expectations in turn are dependent on the hypothesis being tested. Given the table results so far, and the fact that other studies (e.g., Sondheim and Rollerson 1985; Howes and Sondheim 1986) have found slope to be a primary controlling factor, a two-stage nested model may be proposed. First, slope steepness, as reflected by the four classes, is of fundamental importance. Secondly, within any given slope class, knowledge of the physiographic region is of value. The corresponding null hypotheses are: 1) the differences in numbers of slides among slope classes can be explained solely on the basis of the number of active cells occurring in each slope class; and 2) within a given slope class, the differences in numbers of slides among the different physiographic regions is strictly a function of the number of active cells occurring in each region.

Consider first the slope classes (Table A4). With random slide occurrence, the expected number of slides in each class would be entirely dependent on the area in each case. Class 1 contains 107 active cells or 3.4% of the total number of active cells. Thus, it might be expected that 3.4% of the total of 8328 slides (i.e., 283 slides) will be found in class 1. Expected values for the other three classes can be defined as well. Next the value (Observed-Expected)/SQUARE_ROOT (Expected) can be calculated for each class. For class 1 it is (169-283)/SQRT (283) or -6.8. This represents a standardized residual. If the observed and expected values are equal, the residual is 0. Values greater than 1.96 or less than -1.96 (95% confidence interval) may be assumed to be much higher or lower than mere chance would dictate. Classes 1 and 2 have low values (-6.8 and -12.2), whereas the values for classes 3 and 4 are high (8.9 and 6.7). This division of low and high corresponds with the class slide to active cell ratios discussed above (Table A3.)

For each class the value of observed * NATURAL_LOG (observed/expected) may then be calculated. For class 1 it is 169 * LN (169/283) -86.9. These values may then be added for the four classes, and the sum multiplied by 2, to produce a likelihood ratio chi-square statistic of 330 with three degrees of freedom (Table A4). This very high value confirms that the slope steepness is a major factor related to the slides per active cell ratio.

Next comes the question of whether within each slope class the regions are really very different from one another. An evaluation must be made of the expected number of slides for each region nested within each slope steepness class. Thus, for every slope class are the total number of slides (169 for class 1) distributed in the regions purely as a function of the regions' class areas (10, 37, 8, 38, 10, and 4 for class 1)? The expected value for each class-region combination (Table A5) can be determined as follows: multiply the total number of slides for the slope steepness class corresponding to that table position, by the proportion of the total area within that steepness class occurring in the table position. For example, for region 1-class 1 the expected result is: 169 * (10/107) = 15.8.

The observed and the expected numbers may be used to calculate the standardized residuals (Table A6). From the residuals it appears that for the Kumshewa Uplands (region 2), on slopes averaging between 32 and 42° (class 3), the actual number of slides is much less than the expected number. For the Graham Ranges (region 4), on slopes ⩾ 32° (classes 3 and 4), the actual number of slides is much greater than the expected number. The likelihood ratio chi-square may be determined as before, giving a value of 59, with 19 degrees of freedom. This value is high enough to suggest that in general the physiographic regions are significant within the slope classes, as suggested by the examination of the residuals.

If the likelihood ratio chi-square values are added for the slope classes and the regions within the classes, the result is 389. Similarly, the degrees of freedom sum to 22. These numbers represent the totals associated with the analysis of Table A6. The totals can also be calculated by assuming that neither slope nor region is important, and that the number of slides is entirely dependent on the number of active cells in each table position (Table A2). In this scenario, the number of expected slides for any position equals the total number of slides multiplied by the proportion of the total number of active cells found in that position. For class 1-region 1 this becomes 8328 * (10/3153), or 26.4. If this is followed through for the 23 table positions, the likelihood ratio chi-square becomes 389 with 22 degrees of freedom. Thus, roughly 85% of the total chi-square is associated with the slope classes (100% * 330/389) and 15% with the regions within the classes.

It can be concluded that the ratio of slides per active cell is strongly influenced by slope steepness class and to a lesser extent by physiographic region. Within slope classes the regions appear to behave significantly differently; this is manifest primarily in lower than expected ratios for steeper slopes in the Kumshewa Uplands and higher than expected ratios for steeper slopes in the Graham Ranges. The exact cause of these regional differences has not been determined. They may be linked to different geographic positions relative to storm fronts or to differences in regional lithology. Of course other causes may also be responsible.

The above analysis has been limited to physiographic region and slope steepness class. It is an example of the kind of investigation of the active areas which could be carried out with many of the other attributes in the database.

Limitations of the Study

There are several questions the study did not address, in particular, those related to landslide prediction, further use of the data, and the effects of logging:

(1) Can the data for the present study be used effectively to predict where landslides are likely to occur and where they are not likely to occur?

(2) Can the data for the present study be combined with data from other sources to help characterize areas subject to slope failure?

(3) Can the influence of logging activity or road construction on the slope failure rate be gleaned from the data?

The general answer to all three questions is no, for reasons discussed below.

To be able to answer question (1), knowledge of areas both with and without slides is required. For the first four classifications - physiography, precipitation, biogeoclimatic zone, and bedrock geology - summarized data are available for both types of areas. For example, 9.7% and 22.4% represent the area and number of slides, respectively, for the Moresby Ranges with reference to the total area within the Charlottes. Similar statistics are available for, as an example, the Mountain Hemlock (MH) Biogeoclimatic Zone. However, what percentages of the area and slides in the Charlottes are within both the Moresby Ranges and the MH Zone cannot be answered - nor can any other questions for the first four classifications related to cross-referencing.

The situation is more difficult for the last five classifications (land use, elevation, slope steepness, aspect, and slope position), where data are recorded only for cells with slide activity. For example, 64.1% of the slides may occur in cells with average slopes between 32 and 42°, but it is not known whether 64.1% is high or low with reference to the percentage of all slopes which lie between 32 and 42°. Thus, it is not possible to determine whether, for all of the Charlottes or for any given sub-area, there is a relationship between the likelihood of slide activity and slope steepness. Clearly, more complex questions cannot be answered either, such as: Is there a relationship between the presence of slides and certain combinations of slope angle and aspect within specific bedrock and physiographic types?

Question (2) concerns the ease of combining the data from this study with data from other sources. The reason this is problematic is that the level of georeferencing in the study is minimal. That is, there is no way of generating the UTM coordinates for either the slides or the 1-km^2 cells in the active cell database. Each cell can be referenced geographically only by the number of the 1:50 000 mapsheet in which it is located. If the results of the present study were to be examined in conjunction with those of say Landsat image analysis, it would only be possible at the mapsheet level. On the other hand, it would be realistic to compare the characterization of slide-prone areas as determined by the two different approaches. If this were done, great care would have to be taken for reasons related to question (3).

Question (3) asks if the study can be used to assess the impact of logging and road construction. The reader is referred to the hypothetical example of data collection provided in "Purpose and Methodology of the Study" of this critique. Here a slide has occurred in a cell containing logging operations. The characteristics of the slide, not mentioned earlier, are: it is located in the 60% of the cell covered by forest, the slope angle at the initiation point is 37°, and the causes of the slide are natural. The cell is recorded as having experienced logging; however, the inference cannot logically be made that the slide is associated with logging in any way. Note that the area of a typical slide is on the order of 1/1000th that of a cell; the point of failure initiation is smaller still. Consequently, it is quite likely that average conditions for a cell may not represent those for slides within the cell. Where the recording of a class is based on presence or absence instead of an average, the relationship between slide and cell characteristics is even more tenuous.

From this commentary the question arises as to what a study covering the Charlottes would look like if prediction and the assessment of logging impact were the issues. Although a detailed discussion is beyond the scope of this critique, a number of points may be listed:

1. The basic mapping units (or polygons) should have geomorphic significance.
2. Data must be collected for all polygons within a given area, not simply for those experiencing failure.
3. The polygons should be defined as homogeneously as the scale of mapping allows, with respect to both physical and cultural attributes.

4. If the presence or number of occurrences of a particular feature is of major interest, the principal attributes associated with that feature should be collected directly where possible, not extrapolated from the polygon database.
5. The attributes should be carefully chosen so that significant questions can be answered.
6. Data analysis might be regionalized such that, if different failure-related characteristics exist in different areas, this will be evident in the analysis.
7. Some kind of statistical design to the data collection and analysis should be considered.
8. Before the data collection begins, it may be useful to perform detailed analyses with fake data. This can build confidence that the study will be able to address the questions of interest.

As well, it should be recognized that road-related slides may have different causes and may occur in different terrain compared to open slope, clearcut-related slides (Rollerson and Sondheim 1985). If road failures are also of interest, for each polygon the type of road construction and road drainage should be collected, as should the road length and gradient. Alternatively, road data could be collected independently of the polygon descriptions; in this case the relationships between the roads and polygons could be gleaned from overlay techniques, preferably in a geographic information system.

With an appropriate database it would be possible to extend the kind of analysis performed in the last section. Specifically, the occurrence of slides should be able to be related to a series of categorical variables, such as slope class, aspect class, and bedrock class. Among the techniques for doing this are log-linear model analysis and logistic regression (Bishop et al. 1975; Fienberg 1980). These procedures are available in the Statistical Analysis System (SAS 1985) and the Statistical Package for Social Sciences (Norusis 1985). Discriminant analysis (also in SAS and SPSS) is another technique which has been used effectively (Rice and Pillsbury 1982; Rice et al. 1985). A discrete form of discriminant analysis operating on multinomial data has been applied by Bob Pack of Thurber Consultants (Pack 1985). Approaches involving classification and calculation of class statistics have also been developed (Tsukamoto et al. 1982; Lessing et al. 1983; Rollerson et al. 1986).

A robust, statistical-geographical method, more applicable to prediction and/or gauging logging impacts, is not without drawbacks. Undoubtedly it would be expensive. To keep the costs reasonable, satellite image analysis techniques might have a role. However, although this approach looks promising (Sondheim and Rollerson 1985; Howes and Sondheim 1986), it has not yet been tested with real imagery. In conclusion it is clear that the present study is limited for use as a predictive tool or for assessing the effects on the slide rate of logging. As an inventory investigation, where quantification of magnitude and the characterization of slide prone areas are the central issues, the methodology and presentation are appropriate.

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TABLE A1. Observed number of slides as related to physiographic region and slope steepness class

Physiographic region[a]	Slope steepness class[a] 1	2	3	4	Region sums
1	20	10	8	0	38
2	56	350	303	7	716
3	17	308	508	30	863
4	53	693	1007	131	1884
5	17	527	2059	359	2962
6	6	290	1456	113	1865
Class sums ->	169	2178	5341	640	8328

[a] These regions and classes have been redefined. See the text for their definitions.

TABLE A2. Number of 1-km^2 UTM cells as related to physiographic region and slope steepness class

Physiographic region	Slope steepness class 1	2	3	4	Region sums
1	10	5	4	0	19
2	37	184	124	3	348
3	8	139	166	8	321
4	38	326	296	29	689
5	10	257	717	113	1097
6	4	158	484	33	679
Class sums ->	107	1069	1791	186	3153

TABLE A3. Ratios of slides to cells as related to physiographic region and slope steepness class

Physiographic region	Slope steepness class 1	2	3	4	Region sums
1	2.00	2.00	2.00	[a]	2.00
2	1.51	1.90	2.44	2.33	2.06
3	2.13	2.22	3.06	3.75	2.69
4	1.39	2.13	3.40	4.52	2.73
5	1.70	2.05	2.87	3.18	2.70
6	1.50	1.84	3.01	3.42	2.75
Class ratios ->	1.58	2.04	2.98	3.44	2.64

[a] Because there are no cells in this portion of the table, it is left blank here and on Tables A5 and A6.

TABLE A4. Analysis of slope steepness class

Number of slides	Slope steepness class 1	2	3	4
Observed	169	2178	5341	640
Expected	282.6	2823.5	4730.6	491.3
(o-e)/SQRT(e)	-6.8	-12.2	8.9	6.7
o * LN(o/e)	-86.9	-565.4	648.2	169.3

Likelihood ratio chi-square value = 330 (with 3 degrees of freedom)

Note 1: (o-e)/SQRT(e) values represent standardized residuals. Values above or below roughly 2 or -2, respectively, suggest that the observed values are particularly high or low relative to the expected values.

Note 2: The likelihood ratio chi-square value equals the sum of the o * LN(o/e) values multiplied by 2. (For large sample sizes it is similar to the Pearson chi-square statistic, the sum of $(o-e)^2/e$ values, here equal to 317.)

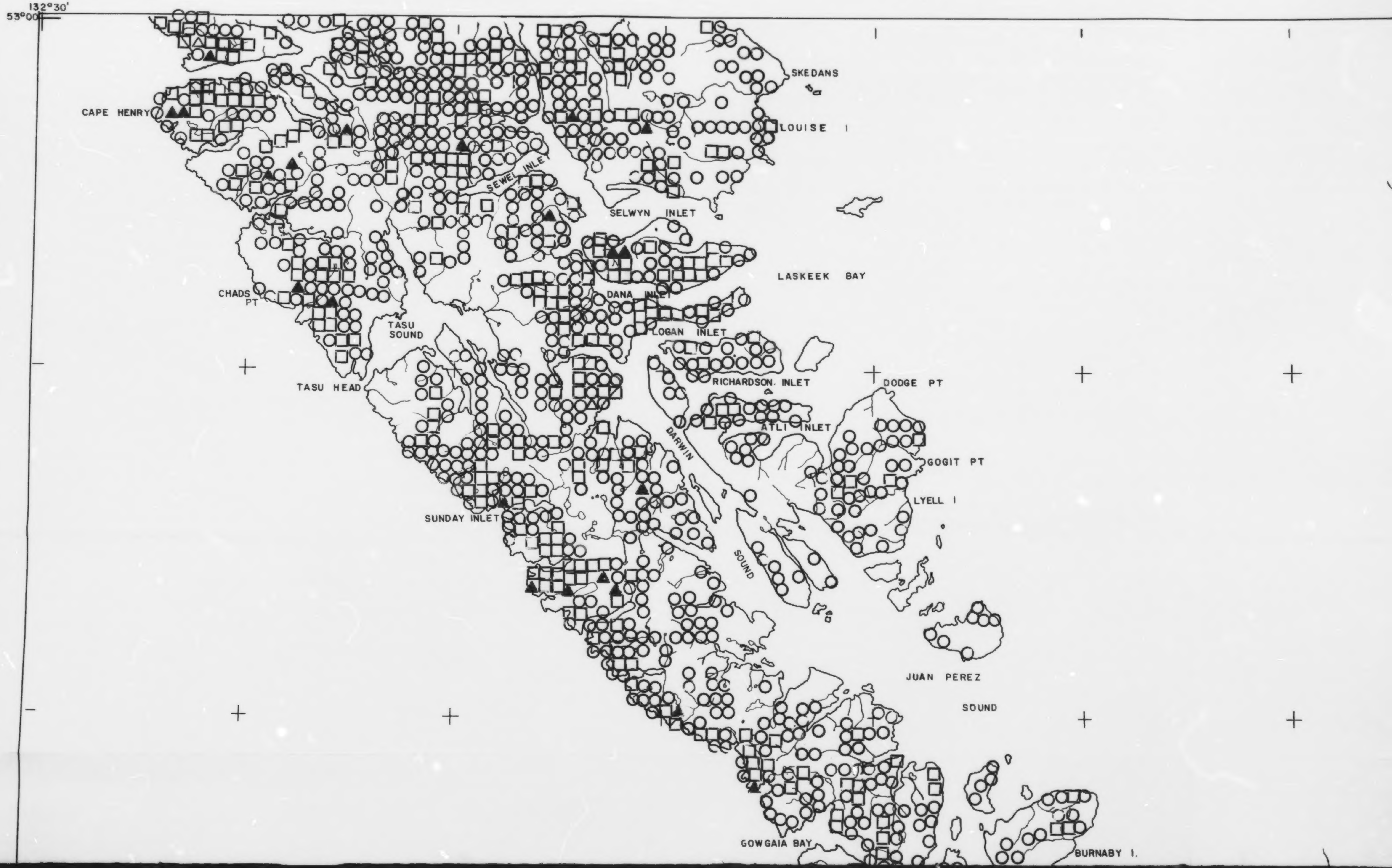
TABLE A5. Expected number of slides as related to physiographic region nested within slope steepness class

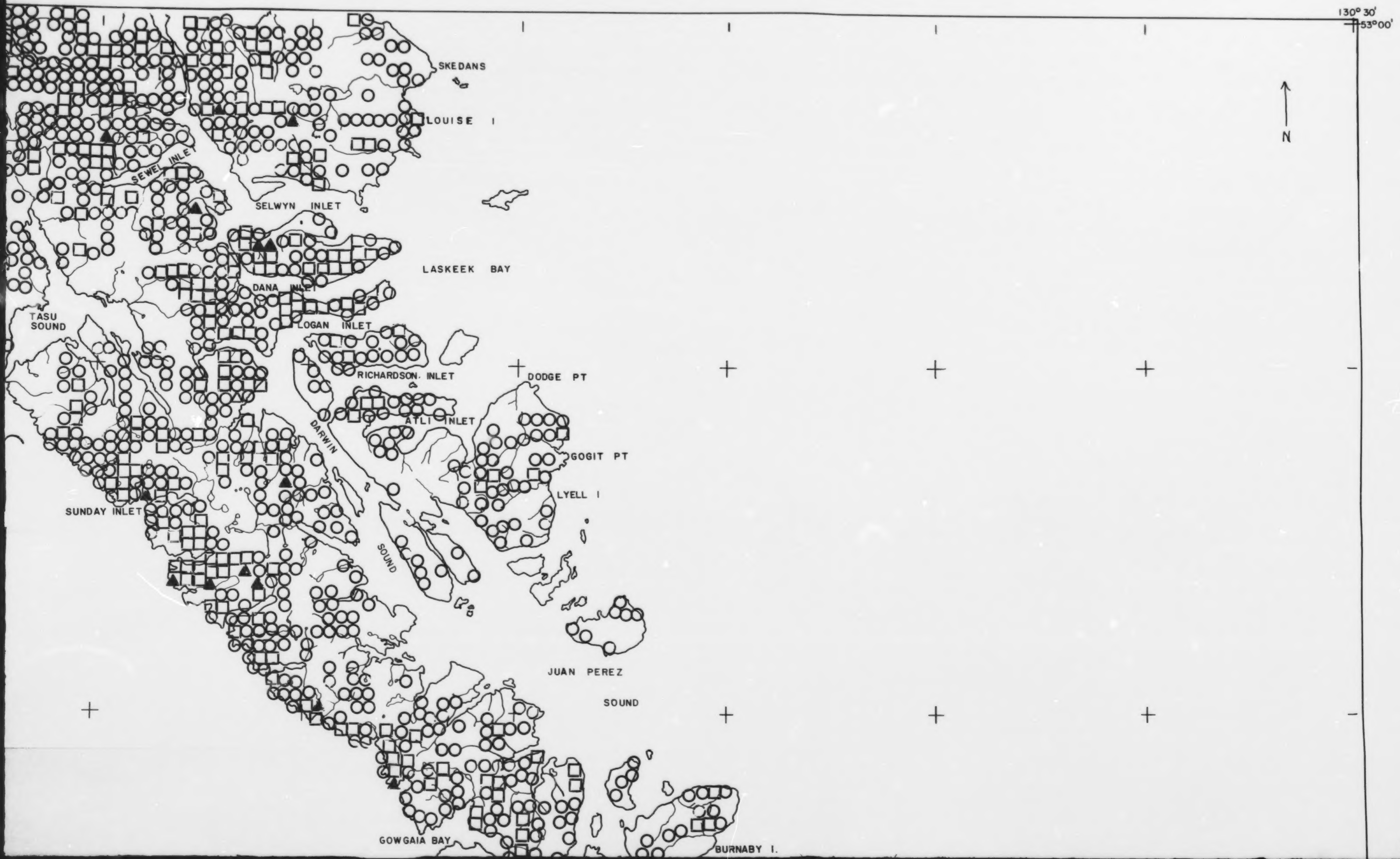
Physiographic region	Slope steepness class				
	1	2	3	4	
1	15.8	10.2	11.9		
2	58.4	374.9	369.8	10.3	
3	12.6	283.2	495.0	27.5	
4	60.0	664.2	882.7	99.8	
5	15.8	523.6	2138.2	388.8	
6	6.3	321.9	1443.4	113.6	
Class sums ->	169.0	2178.0	5341.0	640.0	8328

TABLE A6. Standardized residuals related to physiographic region nested within slope steepness class

Physiographic region	Slope steepness class			
	1	2	3	4
1	-1.1	-0.1	-1.1	
2	-0.3	-1.3	-3.5	-1.0
3	1.2	1.5	0.6	0.5
4	-0.9	1.1	4.2	3.1
5	0.3	0.2	-1.7	-1.5
6	-0.1	-1.7	0.3	-0.1

Likelihood ratio chi-square value = 59 (with 19 degrees of freedom)


132°30'
53°00'
SKEDANS
CAPE HENRY
LOUISE I
SEWELL INLET
SELWYN INLET
LASKEEK BAY
CHADS PT
DANA INLET
TASU SOUND
LOGAN INLET
TASU HEAD
RICHARDSON INLET
DODGE PT
ATLI INLET
DARWIN SOUND
GOGIT PT
LYELL I
SUNDAY INLET
JUAN PEREZ SOUND
GOWGAIA BAY
BURNABY I.


130° 30'
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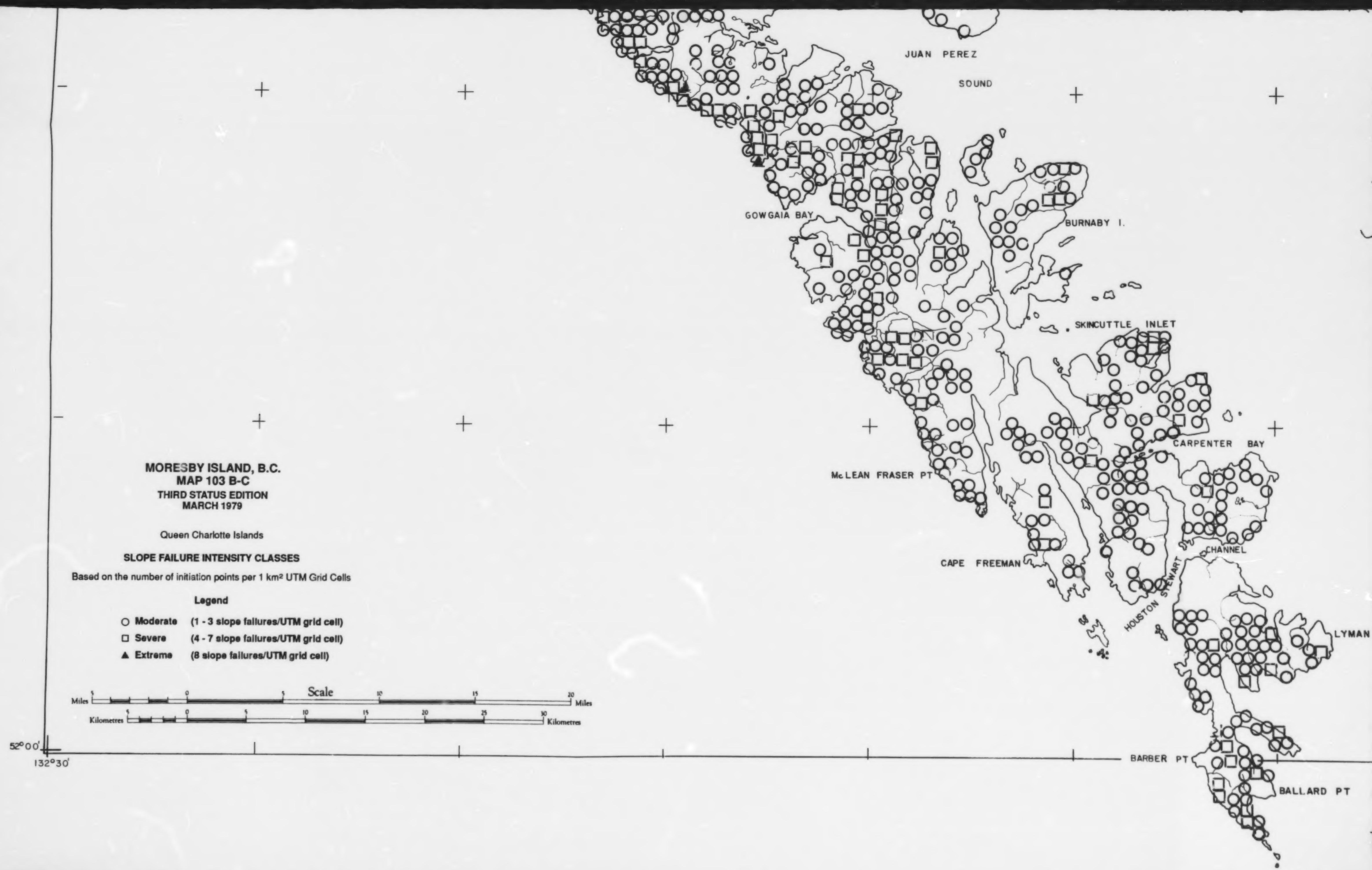
SKEDANS
LOUISE I
SEWEL INLET
SELWYN INLET
LASKEEK BAY
DANA INLET
TASU SOUND
LOGAN INLET
RICHARDSON INLET
DODGE PT
ATLI INLET
DARWIN SOUND
GOGIT PT
LYELL I
SUNDAY INLET
JUAN PEREZ SOUND
GOWGAIA BAY
BURNABY I.


JUAN PEREZ
SOUND
GOWGAIA BAY
BURNABY I.
SKINCUTTLE INLET
CARPENTER BAY
McLEAN FRASER PT
CAPE FREEMAN
HOUSTON STEWART
CHANNEL
LYMAN
BARBER PT
BALLARD PT
52°00'
132°30'
Scale
Miles
Kilometres

MORESBY ISLAND, B.C.
MAP 103 B-C
THIRD STATUS EDITION
MARCH 1979

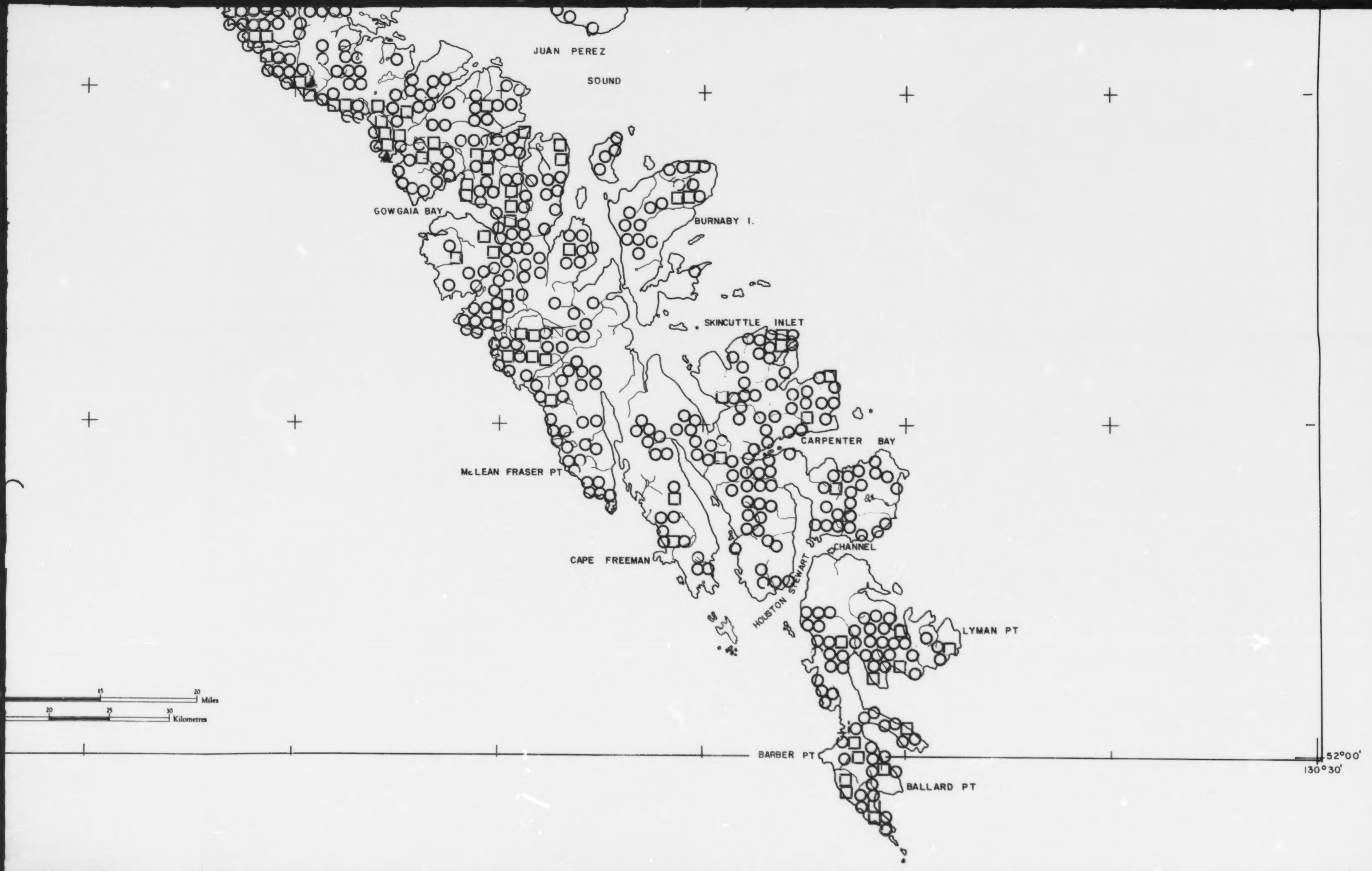
Queen Charlotte Islands

SLOPE FAILURE INTENSITY CLASSES

Based on the number of initiation points per 1 km² UTM Grid Cells

Legend

○ **Moderate** **(1 - 3 slope failures/UTM grid cell)**
□ **Severe** **(4 - 7 slope failures/UTM grid cell)**
▲ **Extreme** **(8 slope failures/UTM grid cell)**


JUAN PEREZ
SOUND
GOWGAIA BAY
BURNABY I.
SKINCUTTLE INLET
CARPENTER BAY
McLEAN FRASER PT
CAPE FREEMAN
HOUSTON STEWART CHANNEL
LYMAN PT
BARBER PT
BALLARD PT
15
20
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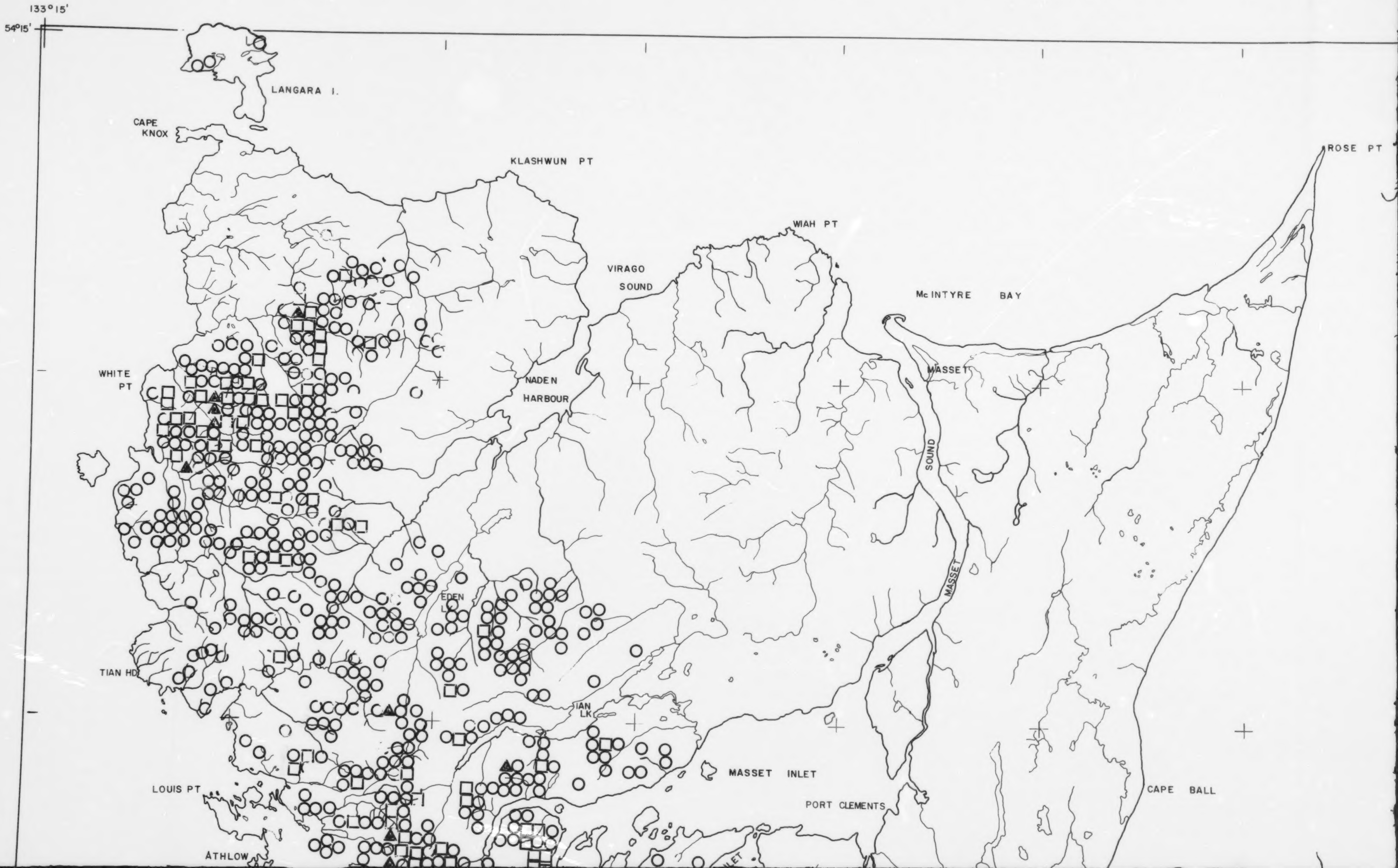
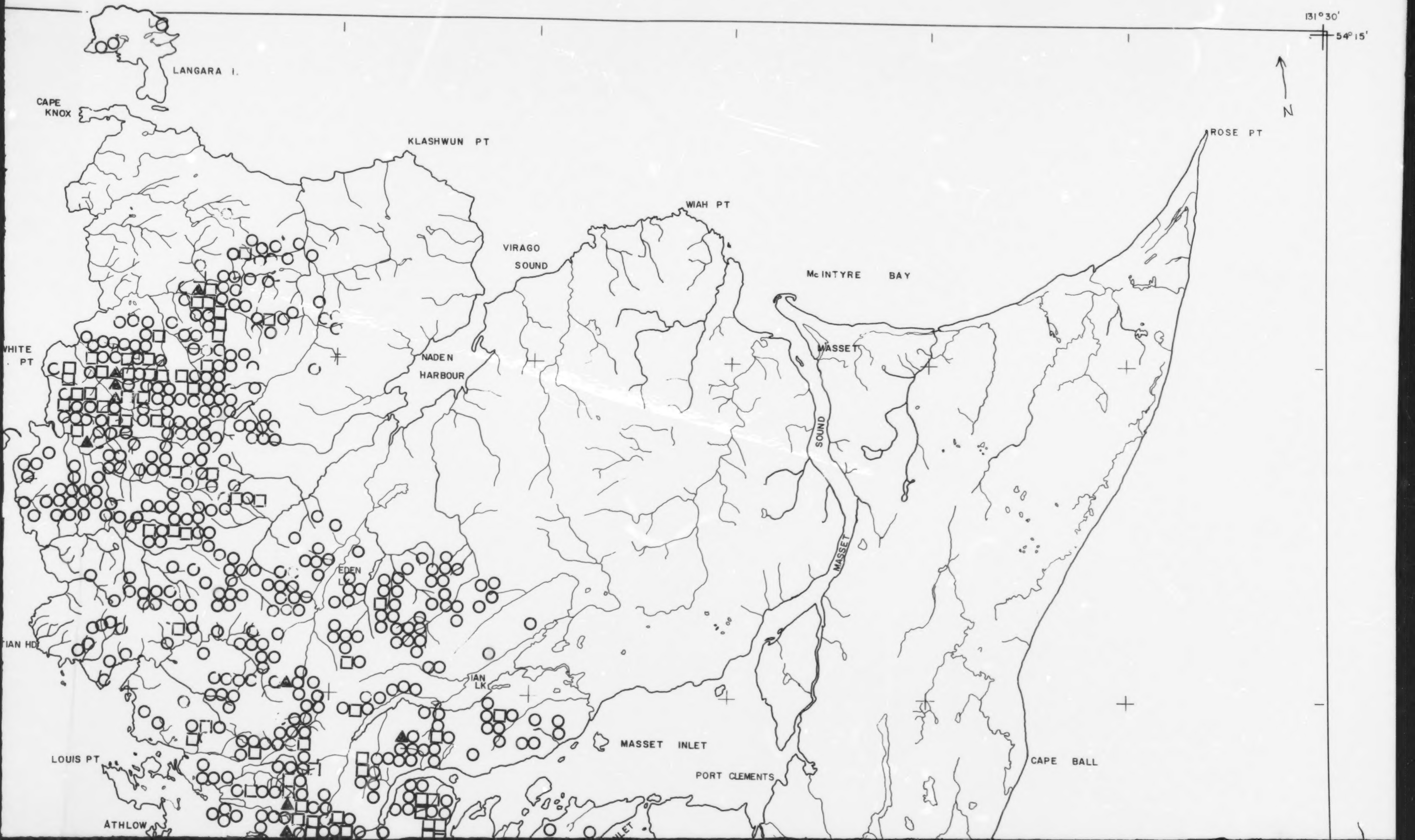
25
30
Kilometres
52°00'
130°30'


133°15'
54°15'
LANGARA I.
CAPE KNOX
KLASHWUN PT
WIAH PT
VIRAGO SOUND
McINTYRE BAY
ROSE PT
WHITE PT
NADEN HARBOUR
MASSET
SOUND
MASSET
EDEN LK
IAN LK
TIAN HD
MASSET INLET
LOUIS PT
PORT CLEMENTS
CAPE BALL
ATHLOW


131°30'
54°15'
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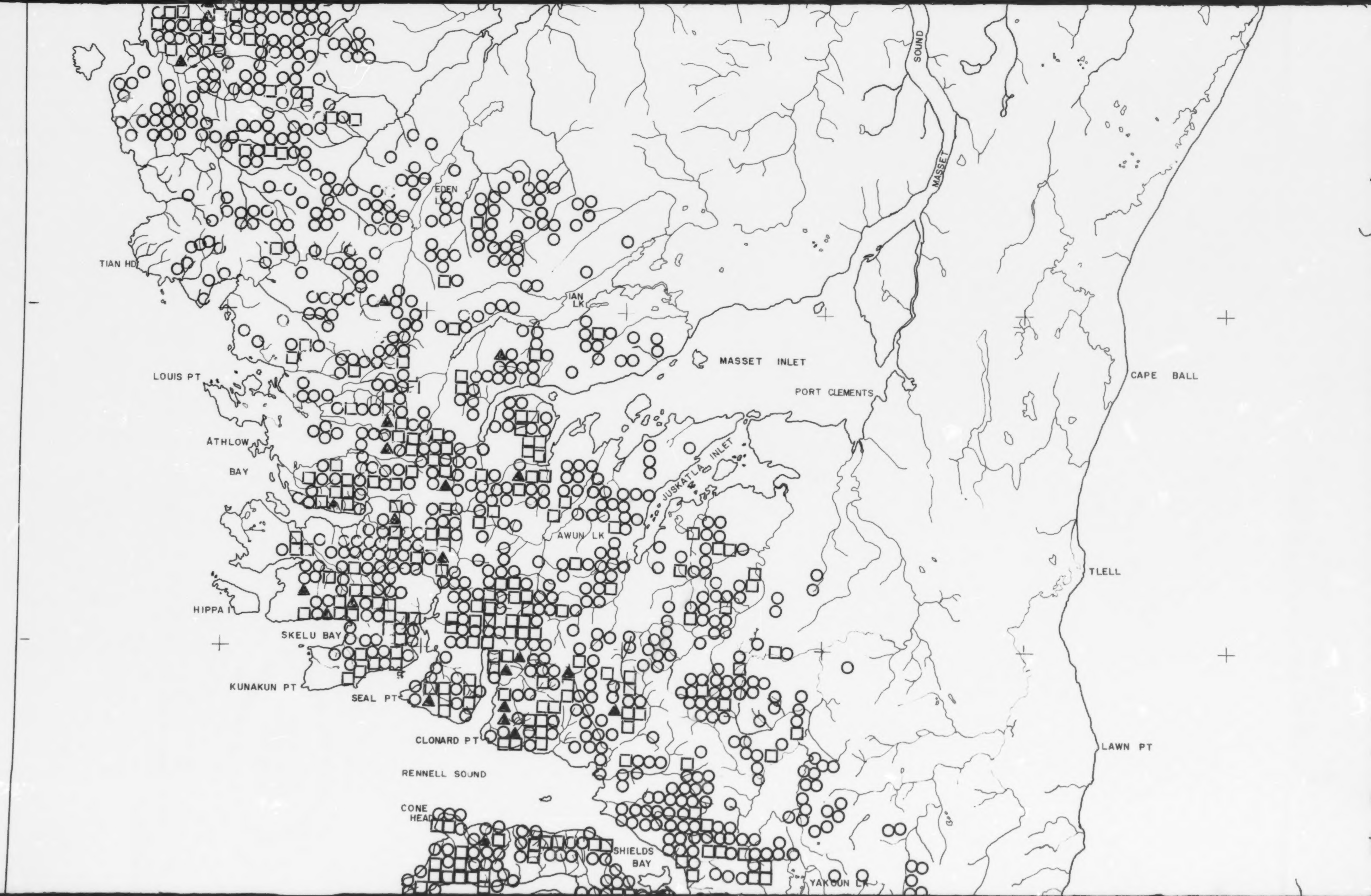
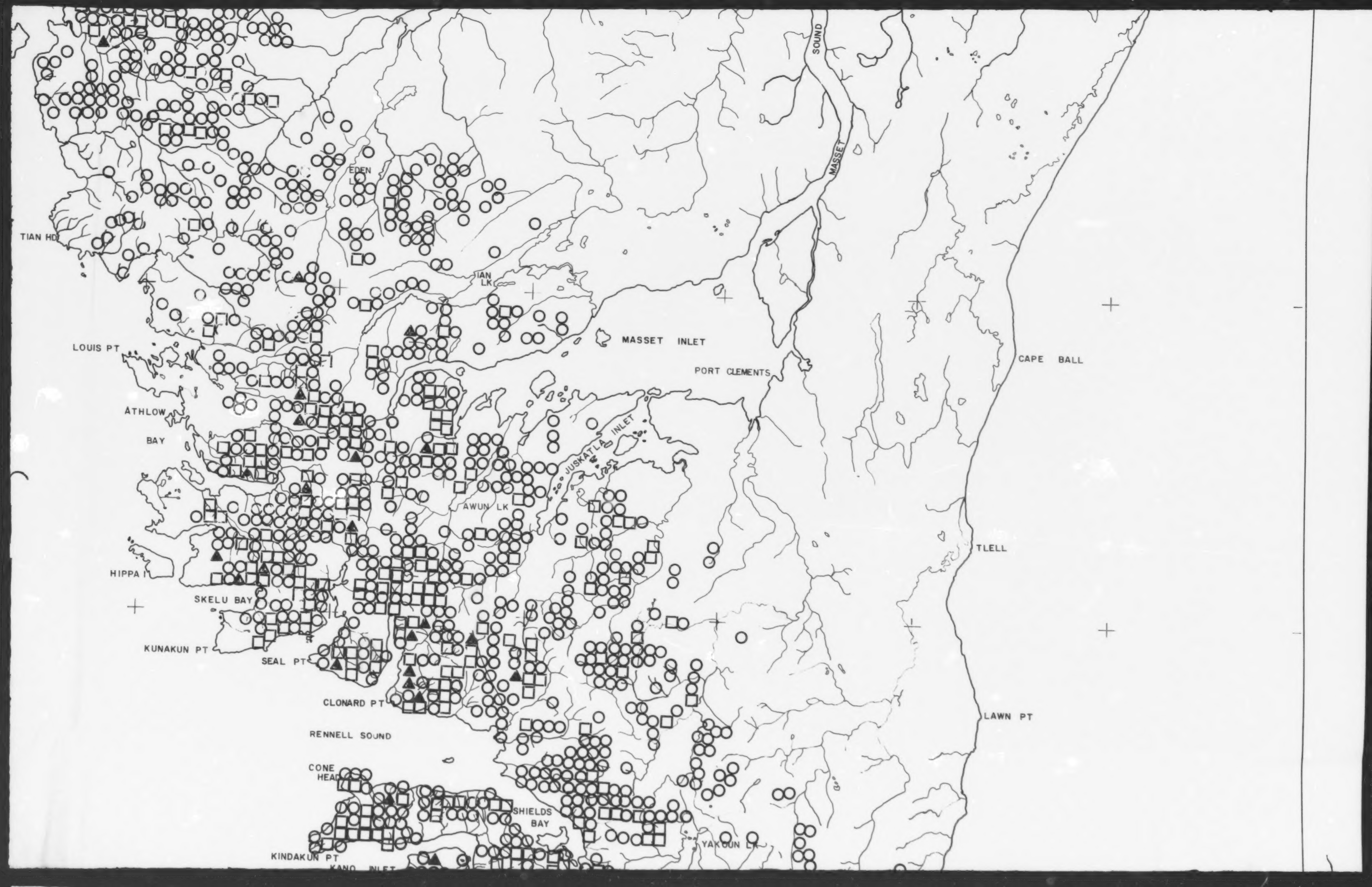
LANGARA I.
CAPE KNOX
KLASHWUN PT
WIAH PT
VIRAGO SOUND
McINTYRE BAY
ROSE PT
WHITE PT
NADEN HARBOUR
MASSET
SOUND
MASSET
EDEN LK
IAN LK
TIAN HD
LOUIS PT
MASSET INLET
PORT CLEMENTS
CAPE BALL
ATHLOW
INLET


SOUND
MASSET
EDEN LK
TIAN HD
IAN LK
MASSET INLET
LOUIS PT
PORT CLEMENTS
CAPE BALL
ATHLOW BAY
JUSKATLA INLET
AWUN LK
TLELL
HIPPA I
SKELU BAY
KUNAKUN PT
SEAL PT
CLONARD PT
LAWN PT
RENNELL SOUND
CONE HEAD
SHIELDS BAY
YAKOUN LK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RENNELL SOUND
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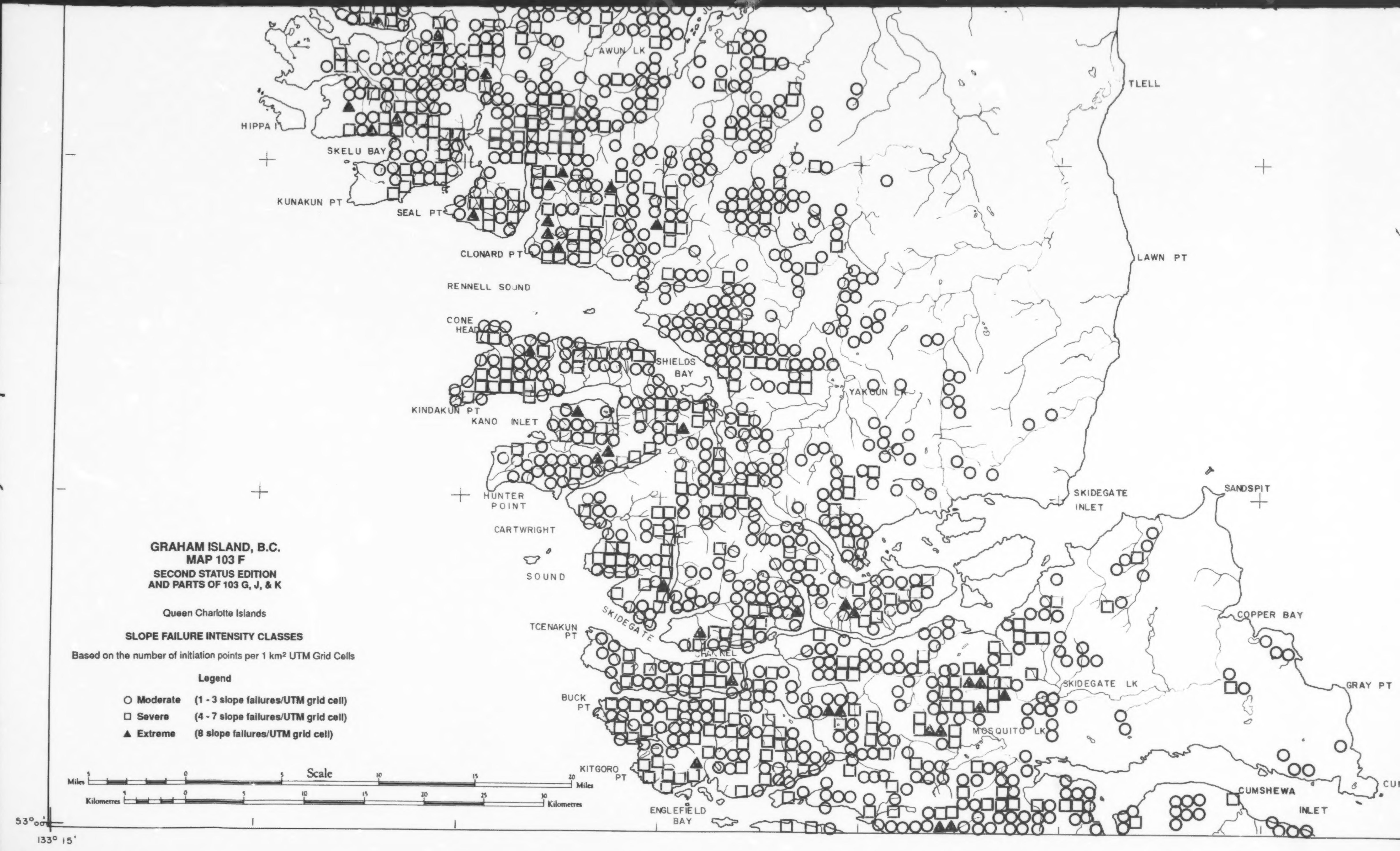
KINDAKUN PT
KANO INLET
YAKOUN LK



GRAHAM ISLAND, B.C.
MAP 103 F
SECOND STATUS EDITION
AND PARTS OF 103 G, J, & K

Queen Charlotte Islands

SLOPE FAILURE INTENSITY CLASSES

Based on the number of initiation points per 1 km² UTM Grid Cells

Legend

○	**Moderate**	**(1 - 3 slope failures/UTM grid cell)**
□	**Severe**	**(4 - 7 slope failures/UTM grid cell)**
▲	**Extreme**	**(8 slope failures/UTM grid cell)**

AWUN LK
TLELL
HIPPA I
SKELU BAY
KUNAKUN PT
SEAL PT
CLONARD PT
LAWN PT
RENNELL SOUND
CONE HEAD
SHIELDS BAY
YAKOUN LK
KINDAKUN PT
KANO INLET
HUNTER POINT
SKIDEGATE INLET
SANDSPIT
CARTWRIGHT
SOUND
COPPER BAY
TCENAKUN PT
SKIDEGATE
CHANNEL
SKIDEGATE LK
GRAY PT
BUCK PT
MOSQUITO LK
KITGORO PT
CUMSHEWA
INLET
CU
ENGLEFIELD BAY
Scale
Miles 5 0 5 10 15 20 Miles
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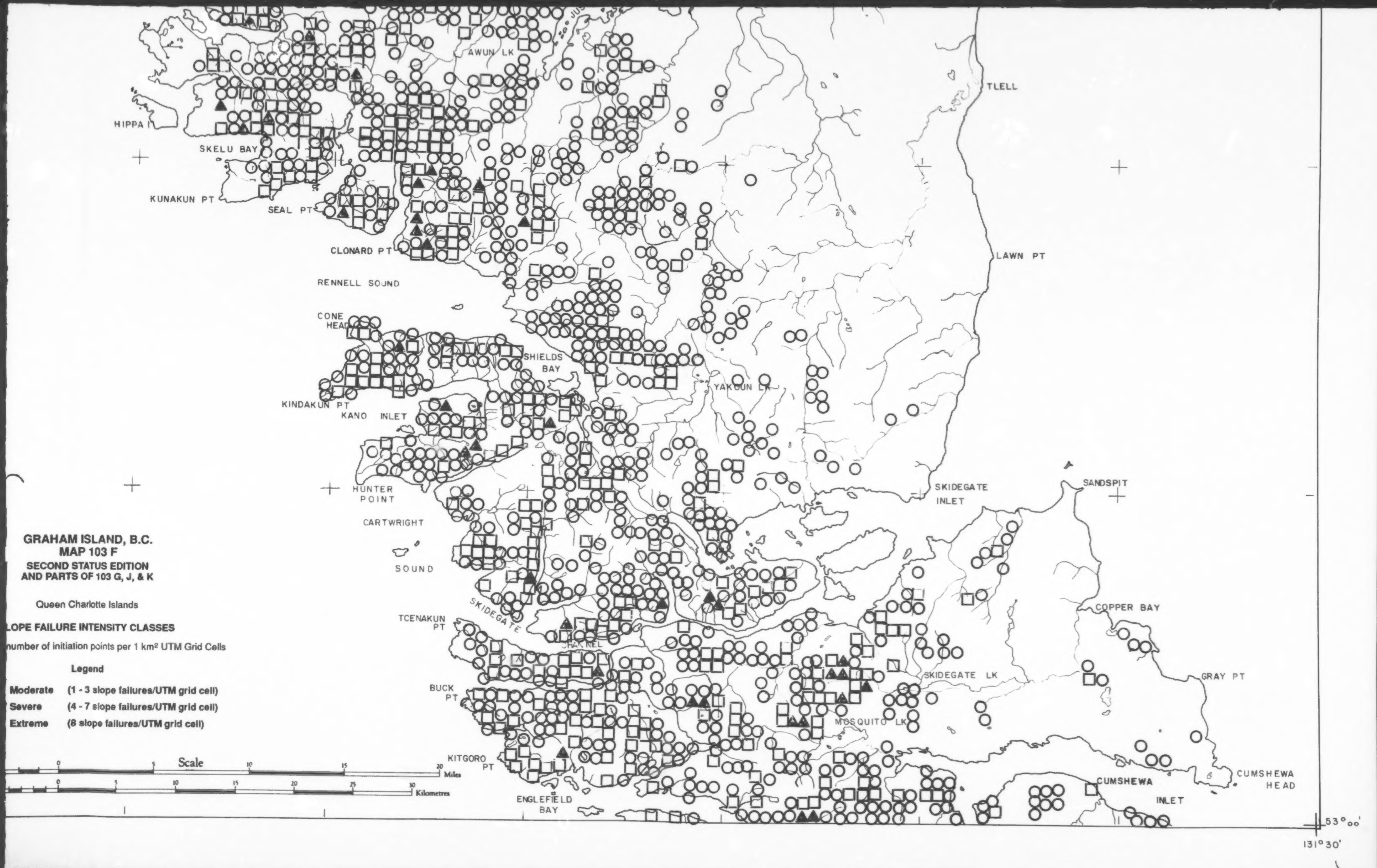
53° 00'
133° 15'


AWUN LK
HIPPA I
SKELU BAY
KUNAKUN PT
SEAL PT
CLONARD PT
RENNELL SOUND
CONE HEAD
SHIELDS BAY
YAKOUN LK
KINDAKUN PT
KANO INLET
HUNTER POINT
CARTWRIGHT
SOUND
SKIDEGATE
CHANNEL
TCENAKUN PT
BUCK PT
KITGORO PT
ENGLEFIELD BAY
TLELL
LAWN PT
SKIDEGATE INLET
SANDSPIT
COPPER BAY
SKIDEGATE LK
GRAY PT
MOSQUITO LK
CUMSHEWA
INLET
CUMSHEWA HEAD
Scale
0
5
10
15
20
Miles
0
5
10
15
20
25
30
Kilometres
53°00'
131°30'

GRAHAM ISLAND, B.C.
MAP 103 F
SECOND STATUS EDITION AND PARTS OF 103 G, J, & K

Queen Charlotte Islands

LOPE FAILURE INTENSITY CLASSES

number of initiation points per 1 km² UTM Grid Cells

Legend

Moderate	**(1 - 3 slope failures/UTM grid cell)**
Severe	**(4 - 7 slope failures/UTM grid cell)**
Extreme	**(8 slope failures/UTM grid cell)**